This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

3 3433 06640983 4

E. DOSKOCZ -

1. Microscope and microscopy, 1957

SUD

THE MICROSCOPY
OF
TECHNICAL PRODUCTS

WORKS OF

ANDREW L. WINTON

PUBLISHED BY

JOHN WILEY & SONS, Inc.

A Course in Food Analysis.
ix+252 pages, 6 by 9, 107 figures. Cloth, $2.00 *net.*

Translation:

The Microscopy of Technical Products.
By Dr. T. F. Hanausek, formerly Professor of Natural History at Vienna. Revised by the author and translated by Andrew L. Winton, Ph.D., with the collaboration of Kate Barber Winton, Ph.D. xii+471 pages, 6¾ by 10, 276 figures. Cloth, $5.00 net.

Revision:

Food Inspection and Analysis.
By Albert E. Leach, S.B., Late Chief of the U. S. Food and Drug Laboratory at Denver. Revised and enlarged by Andrew L. Winton, Ph.D. xix+1090 pages, 6¾ by 10, 120 figures, 40 full-page half-tone plates. Cloth, $8.50 net.

THE MICROSCOPY

OF

TECHNICAL PRODUCTS

BY

DR. T. F. HANAUSEK

Formerly Director of the Gymnasium at Krems on the Danube; Member of Various Imperial Commissions and Learned Societies; formerly Professor of Natural History at Vienna, Analyst of the Government Food Laboratory at Vienna, etc.

REVISED BY THE AUTHOR AND TRANSLATED BY

ANDREW L. WINTON, PH.D.

Formerly Chief of the Chicago Food and Drug Laboratory, Bureau of Chemistry, U. S. Department of Agriculture; formerly in Charge of the Analytical Laboratory of the Connecticut Agricultural Experiment Station, etc.

WITH THE COLLABORATION OF

KATE BARBER WINTON, PH.D.

Formerly Micro-Analyst Bureau of Chemistry, U. S. Department of Agriculture; formerly Microscopist of the Connecticut Agricultural Experiment Station

WITH 276 ILLUSTRATIONS

NEW YORK
JOHN WILEY & SONS, INC.
LONDON: CHAPMAN & HALL, LIMITED

1907

THE NEW YORK
PUBLIC LIBRARY
229629B
ASTOR, LENOX AND
TILDEN FOUNDATIONS
R 1943 L

COPYRIGHT, 1907
BY
ANDREW L. WINTON

Entered at Stationers' Hall

Printed in U. S. A.

4/27

PRESS OF
BRAUNWORTH & CO.
BOOK MANUFACTURERS
BROOKLYN, NEW YORK

AUTHOR'S PREFACE.

SINCE the appearance of J. Wiesner's admirable work, "Einführung in die technische Mikroskopie" (Vienna, 1867), a work which laid the foundation for the scientific study of commercial products, no suitable handbook covering the whole field of technical microscopy has been placed before the public.

In the "Lehrbuch der technischen Mikroskopie," the author has sought to fulfil two important tasks essential in such a work. On the one hand, the book is designed to serve as a reliable scientific guide to the student entering the field of technical microscopy, serving to familiarize him with the methods of investigation, the fundamental principles and the literature of the subject, and preparing him to undertake independent investigations in this branch of applied natural science. The student who uses the book for this purpose should have a general knowledge of the natural sciences, particularly the morphology and histology of organisms, and should also be familiar with the principles of chemistry.

On the other hand, the book is designed to aid in the solution of purely practical problems. It teaches the technical worker how to investigate microscopically commercial raw materials with reference to their composition and suitability for technical purposes, thus enabling him to reach practical conclusions. It should be remembered, however, that the book is neither a treatise on raw materials nor an economic natural history, but, as it were, a precursor of works on these subjects; it brings together the typical raw materials of each natural group and points out the characters common to each. In cases where the origin, harvesting, preparation, and utilization of the materials are briefly treated, thus leading the reader into the realm of economic natural history, the purpose is not so much to make the presentation complete as to show

42X297

the influence which methods of preparation have on the structure of the raw material or to determine how far the characters of the raw material permit its use for technical purposes.

The difficulties encountered in combining two purposes, apparently so different, in limiting the subject matter and in selecting types for study, are not inconsiderable. This handbook is the result of many years' experience as a teacher and expert. May it prove practicable and useful.

DR. T. F. HANAUSEK.

VIENNA, March, 1901.

TRANSLATOR'S PREFACE.

DR. HANAUSEK'S "Lehrbuch der technischen Mikroskopie" is unique in that it teaches the microscopic identification of technical products and at the same time the fundamental principles of vegetable histology and the histology of certain animal materials. The author is distinguished alike as an investigator, a teacher, and a technical expert, and his work is characterized by its scientific accuracy, its clearness, and its utility as a guide in diagnosis.

The translation has been carried out with the cordial coöperation of the author, who has made numerous changes in the original text. Much new matter has been added to the chapters on textile fibers, and the number of practical examples increased from eight to eighteen. The analytical key for woods has been revised so as to include the most important North American species. In this latter work a set of authenticated specimens of American woods, kindly furnished by Prof. Geo. B. Sudworth of the U. S. Forest Service, has proved invaluable. The article on paprika has been omitted.

Twenty seven cuts, included in the German edition, have been dropped, but forty-seven others have been added, so that the total number has been increased by twenty. The cuts new to the work include reproductions of drawings by the author, Professors Piccioli and Tschirch, Dr. Barber, and the translator, some published here for the first time, and a number of illustrations of microscopic apparatus kindly loaned by the well-known houses of Ernst Leitz, Carl Zeiss, and The Bausch and Lomb Optical Company. Acknowlegment for the use of cuts is due the Connecticut Agricultural Experiment Station and also the following publishers: Ferdinand Enke of Stuttgart (publisher of the German edition), Urban and Schwarzenburg of Vienna and

Berlin, Paul Parey of Berlin, Alfred Hölder of Vienna, W. Braumüller of Vienna, G. Masson of Paris, and H. Hassel of Leipzig.

The translation could not have been undertaken but for the able assistance of Dr. Kate G. Barber, who from the first has been identified with the work and is well entitled to a place as collaborator.

It is hoped that this handbook will bring to the attention of English-speaking scientists the importance of analytical histology in the examination not only of foods but of fibers, woods, paper, and other technical products.

A. L. WINTON.

CHICAGO, May 15, 1907.

CONTENTS.

PART I.

APPARATUS AND METHODS.

CHAPTER I.

THE MICROSCOPE.

PAGE

SIMPLE MICROSCOPE 4
COMPOUND MICROSCOPE 5
  Theories 5
    Objectives 6
    Oculars 7
    Illuminating Apparatus 8
  Microscope Stand 8
    Base or Foot 8
    Standard 8
    Stage 8
    Arm 8
    Tube 9
    Nose Piece 9
    Illuminating Apparatus 9
    Mirror 9
    Diaphragm 11
    Substage Condenser 11
  Optical Parts 11
    Objectives 11
    Eyepieces (Oculars) 13

CHAPTER II.

MICROSCOPIC ACCESSORIES.

MICROMETER 14
ABBÉ SUBSTAGE CONDENSER 15
POLARIZATION APPARATUS 15
MECHANICAL STAGE 16

PAGE
CAMERA LUCIDA ... 17
MICROTOME ... 17
MISCELLANEOUS APPARATUS ... 18

CHAPTER III.

MICRO-TECHNIQUE—REAGENTS.

REAGENTS ... 21
  Acids ... 21
  Alkalies ... 21
  Reagents for Specific Reactions ... 22
  Dyes ... 23

PART II.

MICROSCOPY OF THE MOST IMPORTANT TYPES OF TECHNICAL RAW MATERIALS.

CHAPTER I.

STARCH. INULIN.

GENERAL CHARACTERS. POTATO STARCH ... 27
  Formation ... 29
  Chemical Properties ... 33
WHEAT STARCH ... 38
MAIZE STARCH ... 40
RICE STARCH ... 42
BUCKWHEAT STARCH ... 42
OAT STARCH ... 43
MARANTA STARCH, OR BERMUDA ARROWROOT ... 43
CASSAVA STARCH ... 45
SWEET-POTATO STARCH ... 46
CURCUMA STARCH, OR EAST INDIA ARROWROOT ... 46
CANNA STARCH, OR QUEENSLAND ARROWROOT ... 47
YAM STARCH, OR GUIANA ARROWROOT ... 47
BANANA STARCH ... 47
SAGO STARCH ... 47
LEGUMINOUS STARCHES ... 48
INULIN ... 50

CHAPTER II.

VEGETABLE FIBERS.

I. HAIRS (Trichomes) ... 51
    Cellulose ... 54
  Cotton ... 58
    Mercerized ... 65

PAGE
Vegetable Down 68
Vegetable Silk 70
II. FIBERS OF STEMS (Bast Fibers, Fibro-vascular Bundles, etc.) 72
(a) Fibers of Dicotyledonous Plants 73
Flax 73
Hemp 77
Jute 81
Gambo Hemp 83
Sunn Hemp 84
Hop Fiber 87
Nettle Fibers 88
Ramie 90
Paper Mulberry Fiber 92
(b) Fibers of Monocotyledonous Plants 94
Manila Hemp 94
Pita and Sisal Hemp 96
New Zealand Flax 99
III. MICROSCOPIC EXAMINATION OF PAPER 100
Lignin 101
Sizing 103
Identification of Fibers 104
1. Linen-rag Paper 107
2. Hemp Paper 108
3. Cotton-rag Paper 109
4. Jute Paper 109
5. Straw Cellulose 110
6. Mechanical Wood Pulp 116
7. Wood Cellulose, or Chemical Wood Pulp 118
8. Sugar-cane Paper 119
9. Japanese and Chinese Papers 120
10. Miscellaneous Papers 122

CHAPTER III.

ANIMAL FIBERS, MINERAL FIBERS, TEXTILES.

I. ANIMAL HAIRS (Wool, etc.) 123
Sheep's Wool 124
Goat's Wool 130
1. Angora Wool or Mohair 130
2. Cashmere or Thibet Wool 131
3. Common Goat's Wool 132
Cow Hair 133
Distinction between Sheep's Wool, Goat's Wool, and Cow Hair 134
Camel's Hair 137
Alpaca, Vicuña, Llama, Huanaco 139
Shoddy 141
II. SILK AND SILK SUBSTITUTES 144
Common Silk 144
Wild Silks 148

PAGE
Sea Silk. . . . 149
Sinew Fiber. . . . 150
Artificial Silk. . . . 151
III. MINERAL FIBERS. . . . 156
IV. MICROSCOPIC EXAMINATION OF TEXTILE FABRICS. . . . 157
Practical Examples. . . . 159

CHAPTER IV.

STEMS AND ROOTS.

I. WOOD OF DICOTYLEDONS AND GYMNOSPERMS. . . . 174
A. Structure of Wood. . . . 175
Coniferous Woods. . . . 178
Burgerstein's Analytical Key for Spruce and Larch Woods. . . . 192
Broad-leaved Woods of the Temperate Zone. . . . 196
Tropical Broad-leaved Woods. . . . 206
B. Physico-technical Properties of Woods; Notes on Cell Contents. . . . 207
1. Color. . . . 207
2. Hardness. . . . 208
C. Analytical Key for the Identification of the Most Important Economic Woods, with Descriptions of the Species. . . . 211
D. Dyewoods. . . . 243
Yellow Woods. . . . 244
Old Fustic. . . . 244
Young Fustic. . . . 246
Distinction of Old Fustic from Young Fustic. . . . 249
Barberry. . . . 250
Blue Woods. . . . 251
Logwood. . . . 251
Red Woods. . . . 252
E. Cork Woods. . . . 253
II. MONOCOTYLEDONOUS STEMS. . . . 255
Rattan. . . . 255
Fibro-vascular Bundles. . . . 258
Other Stems of Monocotyledons. . . . 261
III. SUBTERRANEAN ORGANS. . . . 262
Monocotyledonous Roots and Rhizomes. . . . 262
Turmeric. . . . 262
Orris Root. . . . 266
Dicotyledonous Roots and Rhizomes. . . . 268
Alkanna Root. . . . 269
Soapwort Root. . . . 269
Chicory. . . . 271
IV. BARKS. . . . 274
Cork. . . . 274
Oak Bark. . . . 281
Quillai Bark. . . . 288
V. FINAL COMMENTS. . . . 290
VI. PRACTICAL EXAMPLES. . . . 293

CHAPTER V.

LEAVES.

PAGE

SUMACH 300
- 1. Sicilian 301
- 2. Venetian 303
- 3. Myrtle-leaved 304

MISCELLANEOUS LEAVES 309

CHAPTER VI.

FLOWERS AND PARTS OF FLOWERS.

INSECT POWDER 310

CHAPTER VII.

FRUITS AND SEEDS.

I. KINDS OF FRUITS. MORPHOLOGY 324

II. THE SEED 329

III. MICROSCOPIC INVESTIGATION OF TYPICAL EXAMPLES OF TECHNICAL FRUITS AND SEEDS 334
- Wheat 334
  - The Examination of Flour with Reference to its Identity and Purity 342
    - 1. Color 343
    - 2. Mechanical Condition 343
    - 3. Ash 345
    - 4. Microscopy 346
- Barley—Chaff of Rice and Millet 349
  - Barley and Malt Coffee 354
  - Weinzierl's Method of Qualitative and Quantitative Mechanico-Microscopical Analysis 354
- Oil Cakes 358
  - Cottonseed Cake and Cottonseed Meal 361
  - Kapok Cake 368
  - Pumpkin-seed Cake 369
  - Ground Olive Stones 371
    - Detection in Pepper 374
  - Niger Cake 375
  - Madia Cake 377
  - Sunflower Cake 377
  - Sesame Cake 380
  - Linseed Cake and Linseed Meal 384
  - Peanut Cake 387
  - Rape Cake 392
  - Poppy Cake 393
  - Hemp Cake 395
  - Beechnut Cake 397
  - Palm-nut Cake 400

PA
Cocoanut Cake.. 4
Miscellaneous Cakes.................................. 4
Myrobalans... 4
Ivory Nut or Vegetable Ivory......................... 4
Polynesian Ivory Nut................................. 4

CHAPTER VIII.

TEETH, BONE, HORN, ETC.

I. TRUE BONES.. 4
II. TEETH.. 4
True Ivory... 4
Hippopotamus Ivory................................... 4
Walrus Ivory... 4
Narwhal Ivory.. 4
Sperm-whale Ivory.................................... 4
III. HORN, TORTOISE-SHELL, AND WHALEBONE............... 4
Horn... 4
Tortoise-shell....................................... 4
Whalebone.. 4

CHAPTER IX.

MICROCHEMICAL ANALYSIS.

COMPARATIVE CRYSTAL ANALYSIS........................... 4
Fusion Tests... 4
Solution Tests....................................... 4
INDIVIDUAL CRYSTAL ANALYSIS............................ 4
Barium... 4
Calcium.. 4
Gold... 4
Potassium.. 4
Sodium... 4
Formic Acid.. 4
Citric Acid.. 4

PART I.

APPARATUS AND METHODS.

HANDBOOK
OF
TECHNICAL MICROSCOPY.

CHAPTER I.

THE MICROSCOPE.[1]

According to the definition of Dippel,[2] the microscope is an optical instrument that enlarges an object (or part of an object) which of itself subtends too small a visual angle (less than 0.5 minute) to be clearly visible, so that the object itself and its details are distinctly evident to the observer.

This enlargement, known as "magnification," is brought about in various ways.

---

[1] The construction, manipulation, and theories of the microscope are here briefly treated; more detailed descriptions will be found in the following works:

Behrens: Guide to the Microscope in Botany (Trans. by Hervey). Boston, 1885. Carpenter and Dallinger: The Microscope and its Revelations. London, 1901. Chamot: Chemical Microscopy. New York, 1915. Czapski: Theorie der optischen Instrumente. Breslau, 1893. Dippel: Handbuch der allgemeinen Mikroskopie. 1882. I. Theil: Das Mikroskop und seine Anwendung; II. Theil: Anwendung auf die Histologie der Gewächse. 2. Aufl. 1896. *Idem:* Grundzüge der allgemeinen Mikroskopie. Braunschweig. 1885. Frey: Das Mikroskop und die mikroskopische Technik. Leipzig, 1881. Gage: The Microscope. Ithaca, 1914. Hager u. Mez: Das Mikroskop und seine Anwendung. Berlin, 1899. Harting: Das Mikroskop. Braunschweig, 1866. Nägeli u. Schwendener: Das Mikroskop. Leipzig, 1877. Schacht: Das Mikroskop. Berlin, 1855. Strasburger: Das bot. Practicum. Jena, 1897. Strasburger and Hillhouse: Handbook of Practical Botany. London, 1900. v. Thanhoffer: Das Mikroskop und seine Anwendung. Stuttgart, 1880. Vogl: Commentar zur Österreich. Pharmakopöe. II. Band: Allgemeiner Theil. Wien, 1892. Wiesner: Einleitung in die technische Mikroskopie. Wien, 1867. Winslow: Elements of Applied Microscopy. New York, 1905.

[2] Realenzyklopädie der gesammten Pharmacie. 1. Aufl., 6, 699.

Simple Microscope.

If an object is placed between a biconvex lens and its focal point an enlarged image is obtained in a position further removed from the

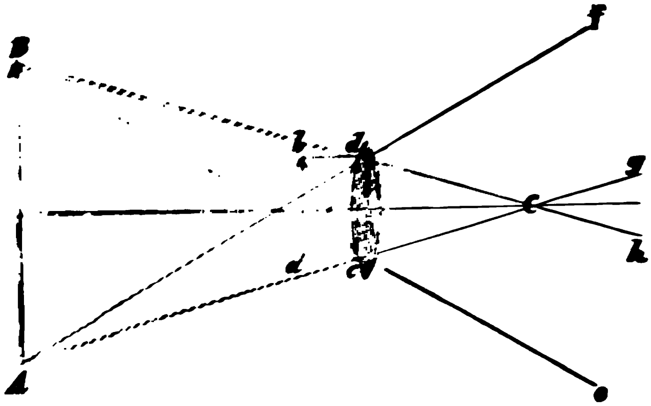


Fig. 1. Formation of Image by a Simple Lens. (Thanhoffer.)

lens than the object itself. In Fig. 1, *dc* represents the lens, *ab* the object, and *bd* and *ac* two rays parallel to the optical axis. The rays are refracted by the lens and collected in the focal point *C*, beyond which they diverge toward *g* and *h*, where they meet the retina of the eye; while the rays *ad* and *bc* are refracted toward *j* and *e* and there also meet the retina. The eye finds the enlarged image at *AB*, where the lines formed by extensions of the refracted rays (*jA–gA* and *eB–hB*) meet. A lens (or a combination of lenses) which brings about this result is known as a *simple microscope*. Lenses of this description are usually mounted in metal, hard rubber, or horn, and are often so arranged that two or more can be used in conjunction. A **Pocket Lens** with a swinging cover, which also serves, when open, as a handle, is shown in Fig. 2. Three adjustable **Lens Holders**, with standards, are shown in Fig. 3. In the more convenient form known as the **Dissecting Microscope** (Fig. 4), the lens is carried on an arm which is raised or lowered for focusing by a rack and pinion, while the object is placed on a glass slide or watch glass supported by a stage and may be illuminated by light reflected upward from a mirror beneath.

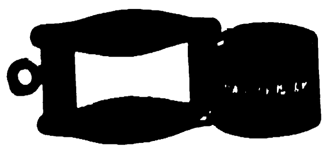


Fig. 2. Pocket Lens. (Bausch and Lomb.)

Compound Microscope.

When magnification is effected by two lenses or two combinations of lenses, one (objective) producing an enlarged image, the other (ocular or eyepiece) enlarging this image, the instrument is known as a compound microscope or simply as a microscope in contradistinction to a lens or simple microscope.

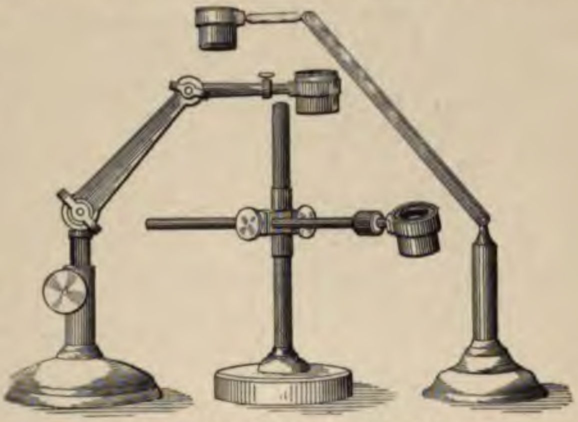


FIG. 3. Lens Holders. (LEITZ.)

THEORIES OF THE COMPOUND MICROSCOPE.—According to the older theories[1] (which are sufficient for our purpose), magnification by a compound microscope is explained as follows:

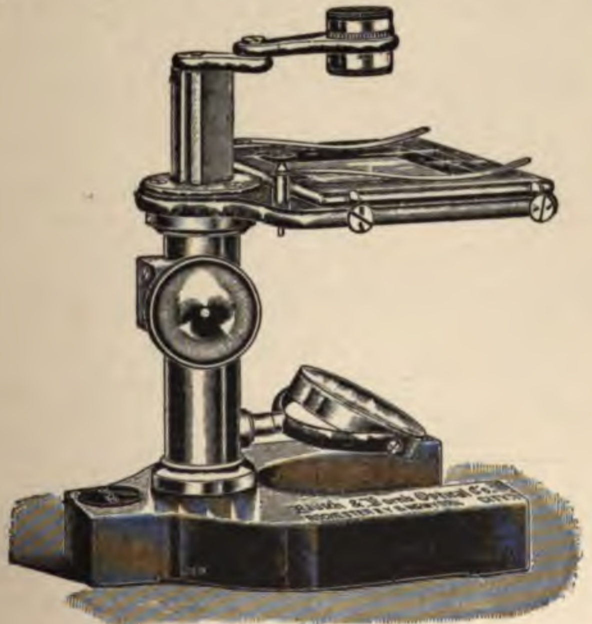


FIG. 4. Bausch and Lomb Dissecting Microscope.

---

[1] Prof. ABBÉ'S more recent theories as to the formation of images are not here considered.

junction with the ocular lens. The image formed by the objective is brought within the field of vision by the collective lens and is finally magnified by the ocular proper.

Illuminating Apparatus.—The microscope, through its two systems of lenses (the objective and the ocular), performs three optical functions: (1) concentration of rays, (2) formation of an image, and (3) magnification. For this, however, sufficient light to illuminate the object is essential.

According to DIPPEL, the illuminating apparatus must fulfil the following conditions: (1) it must be so constructed as to permit the projection of a cone of light on the object at will, either in the direction of the axis of the instrument or in any oblique direction; (2) it must have an aperture for the passage of light, the size of which can be altered so as to regulate the quantity of light according to the nature of the object. These results are secured by means of the mirror and the diaphragm, supplemented often by a substage condenser (p. 15).

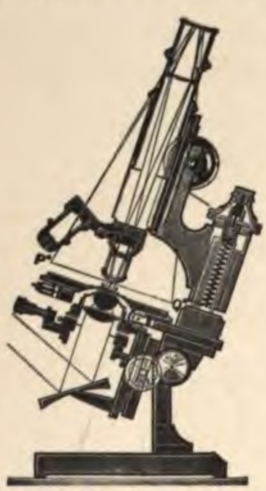


FIG. 9. Section of Compound Microscope. (LEITZ.)

MICROSCOPE STAND (Figs. 9–15).—The essential parts are the base, the standard, the stage, the arm, with fine and coarse adjustment the tube, and the illuminating apparatus (substage).

The **Base** or **Foot** is usually horseshoe- or Y-shaped. It is made of cast brass or iron, often weighted with lead, and should be of considerable weight so as to bring the center of gravity as low as possible, thereby giving the instrument stability.

The **Standard** consists of a single or double cylinder or prism and in the better grade of instruments is jointed below the stage.

The **Stage** is a square or round shelf, with a hole in the middle to admit light from below, on which is placed the glass slide with the object under examination. If the instrument is bent at the joint so that the stage is considerably out of a horizontal position, the slide is held in place by spring clips.

The **Arm**, which carries the tube of the microscope with its optical parts, is provided with two adjustments operated by thumb screws; one (the coarse adjustment) consists of a rack and pinion, the other (the fine adjustment) of a micrometer screw for accurate focusing.

The **Tube** is provided at the lower end with a thread to which are attached the objectives. An inner or draw tube carries the eyepiece at the upper end. This draw tube is graduated so that the length of the combined tubes, in any given position, may be readily determined.

Although a **Nose Piece** is not an absolute necessity, it is an inexpensive addition to the microscopic equipment that greatly facilitates work and saves wear and tear of the objectives. It consists of a simple revolving device by means of which any one of the two to four objectives attached to it may be instantly brought into service.

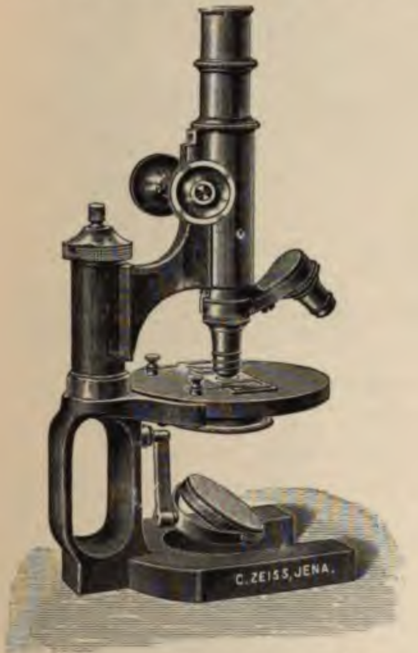

C. ZEISS, JENA.

FIG. 10. Zeiss Microscope, Stand V A.

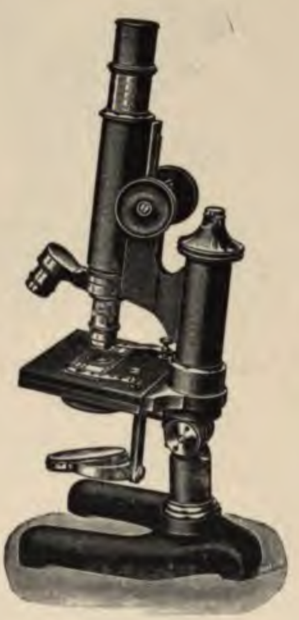


FIG. 11. Leitz Microscope, Stand D.

The **Illuminating Apparatus,** consisting of mirror, diaphragm, and, in the better instruments, condenser, is borne wholly or in part on the substage which is attached either directly to the bottom of the stage or to an arm projecting downward from it.

The **Mirror** is usually plane on one side and concave on the other. It is so arranged that it can be turned in any direction so that light may be projected against the object whatever the position of the instrument.

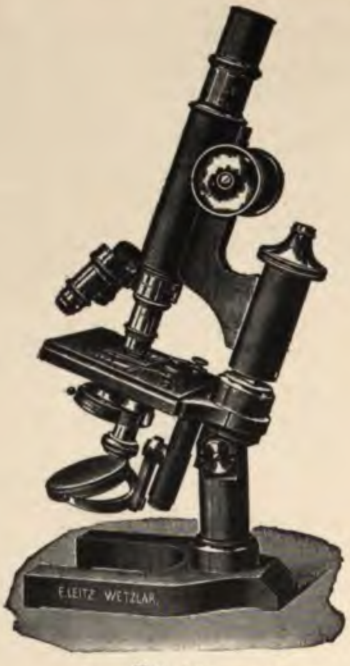

E. LEITZ WETZLAR.

FIG. 12.
Leitz Microscope, Stand **II C.**

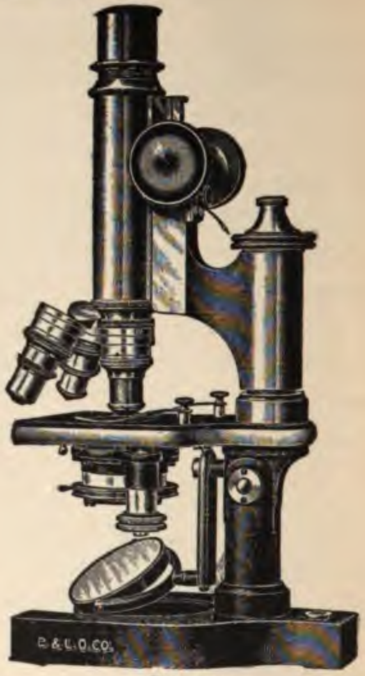


FIG. 13.
Bausch & Lomb Microscope, Stand BB 8.

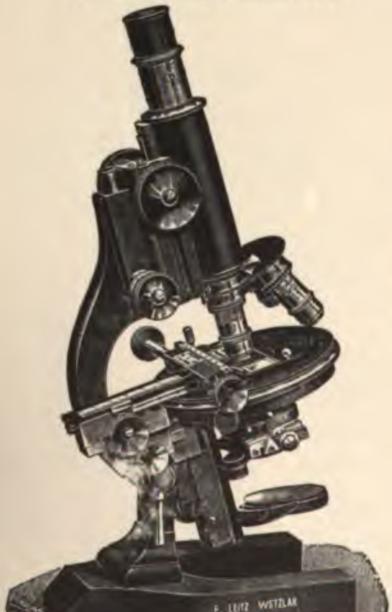


FIG. 14. Leitz Microscope, Stand B.

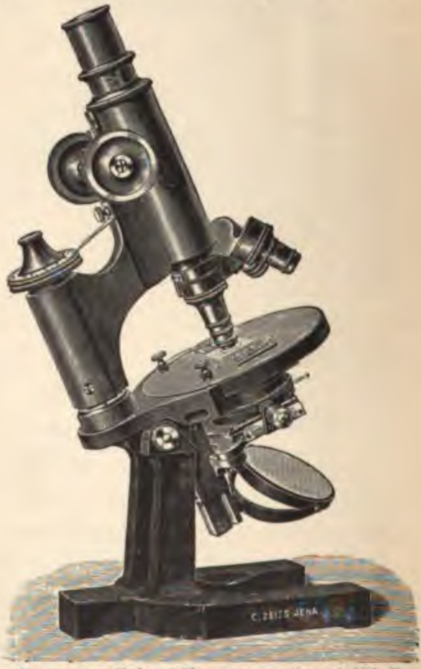


FIG. 15. Zeiss Microscope, Stand IV C.

In its simplest form the **Diaphragm** consists of a series of different-sized apertures for regulating the amount of light. The apertures may be in the center of detachable discs or arranged in a circle about the center of a single revolving disc. A more convenient form is the **Iris Diaphragm** (Fig. 16) consisting of a series of sickle-shape pieces of thin steel so arranged that they form a central opening which may be enlarged or reduced in size by means of a lever. In some instruments there are two of these diaphragms, one above, the other below the condenser.

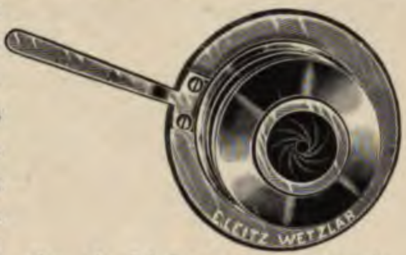


FIG. 16. Iris Diaphragm. (LEITZ.)

The **Substage Condenser** is described under the head of Accessories (p. 15).

Figs. 10 and 11 show inexpensive stands suitable for ordinary work, Figs. 12 and 13, somewhat better instruments meeting the requirements of the advanced worker. The instruments shown in Figs. 14 and 15 represent a high grade of excellence.

OPTICAL PARTS.—The **Objectives** (Fig. 17) consist of a system of lenses mounted in brass, with a thread for attachment to the lower end of the tube either directly or by means of a nose piece. The magnification is increased by increasing the number of double lenses (of crown and flint glass) and at the same time the illuminating power is increased. This increased magnification could also to some extent be secured by increasing the curvature of the lens, but this would be impracticable because of the loss of light if for no other reason.

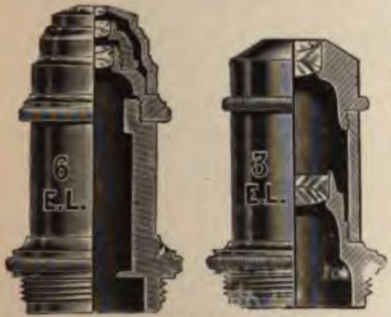


FIG. 17. Objectives. (LEITZ.)

Objectives are designated either by their focal lengths, which range from 2 inches to 1/16 inch or by arbitrary numbers (1–9, etc.). The focal length is an optical value of no real significance to the worker. It is a common error to mistake the working distance, that is the distance between the lower lens of an objective and the slide, for the focal length.

Angular Aperture.—The number of rays which enter an objective and are carried to the plane of the image depends on the light cone whose apex lies at the object (or rather the point of the object that emits the light) and whose base corresponds with the breadth of the lens, or rather with that of the light opening of the system of lenses formed by the mounting. The angle of this cone is the angular aperture (Fig. 18).

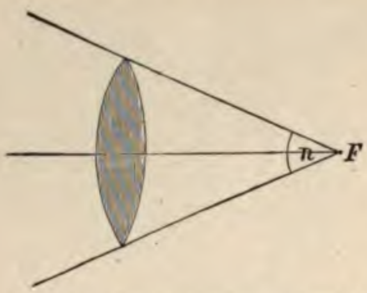


FIG. 18. Lens showing, *n*, Angular Aperture and, *F*, Focal Point. (THANHOFFER.)

Numerical Aperture.—Formerly it was supposed that the power of an objective to collect a greater or lesser amount of light was dependent on the angular aperture, but more recent investigation has shown that the true measure is the sine of half of the angular aperture times the refractive index of the medium. ABBÉ designates this product (n sine $u=a$) the numerical aperture.

The numerical aperture of ordinary dry objectives (with air between the mounted object and the objective) can not exceed unity, but in the so-called immersion lenses is considerably greater. In these latter a drop of water or, in the case of homogeneous immersion objectives, a

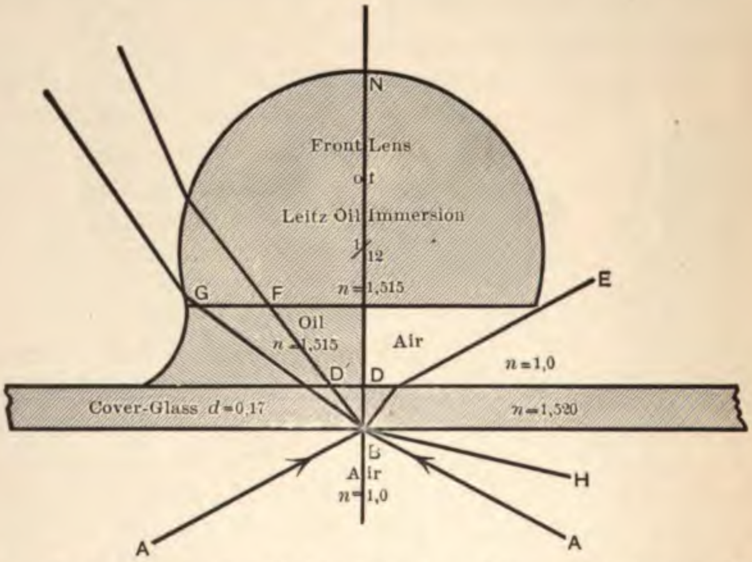


FIG. 19. Showing Comparative Merits of Oil Immersion and Dry Systems. (LEITZ.)

drop of concentrated cedar oil, which has the same refraction and dispersion as the crown glass, fills the space between the cover glass and the objective, and the loss of light due to refraction in passing from glass to air and again to glass is avoided (Fig. 19).

The following examples given by DIPPEL illustrate the significance of the term "numerical aperture" as applied to dry and immersion objectives: "If we have two dry objectives with angular apertures respectively 60° and 120°, the first will not have a numerical aperture half that of the second but in the ratio of the sine of 30° (=0.5) to the sine of 60° (=0.87) or as 1:1.74. If we have a dry and a water immersion objective both with an angular aperture of 120°, the numerical apertures are not the same, but that of the water immersion is n (=1.33) times as great as the other, or $1.33 \times 0.87 = 1.14$. From this it is clear that certain oblique rays which play an important rôle in the formation of the image are utilized in the immersion objectives, which are lost in the dry objectives, even in those with the highest possible numerical aperture (=1) and angular aperture (=180°); and further, that immersion objectives under like conditions are much more efficient than dry, the numerical apertures reaching in practice about 1.20 in water immersions and about 1.35 in oil immersions or in theory 1.33 and 1.52 respectively."

Eyepieces (**Oculars**).—The theory of the eyepiece has already been explained (pp. 6 and 7). The optical parts are mounted in metal cylinders which are introduced into the upper end of the microscope tube. Eyepieces are designated either by their focal lengths (½ inch–2 inches) or by Roman or Arabic numbers.

CHAPTER II.

MICROSCOPIC ACCESSORIES.

Micrometer.—The simplest method of measuring a microscopic object is to place it on a graduated scale etched on a slide (**Stage Micrometer**) and read the dimensions through the microscope. It is, however, seldom practicable to use a stage micrometer directly since it is exceedingly difficult and inconvenient to so place the object that it will coincide with the scale, to say nothing of the danger of injuring the fine divisions (often .01 mm. apart).

A more practicable device, which is now almost universally employed, is the **Eyepiece Micrometer**, consisting of a scale mounted in an eyepiece so that its divisions can be read by the eye-lens. By its use any object or part of an object can instantly be made to coincide with the scale and measured. Since, however, it is the magnified object, not the object itself, that is compared with the scale, the direct readings are not the actual dimensions, although they are readily converted into such by the use of a factor which is constant for the same objective and tube length.

Calibration.—To determine this factor a stage micrometer with, for example, the scale of 1 mm. divided in 100 divisions (1 division =0.01 mm.) is placed on the stage and so adjusted that a certain number of divisions of the eyepiece micrometer cover a certain number on the stage micrometer, both of which are carefully counted. If five divisions of the stage scale (=0.05 mm.) cover 20 divisions of the eyepiece scale then the value of each division of the latter is 0.05 mm. ÷ 20 = 0.0025. If an object, examined with the same objective and tube length as above, is covered by 50 divisions of the eyepiece scale, its true size is 50 × 0.0025 = 0.125 mm. In the same manner the factors for the other objectives may be determined, using always a definite tube length. Micromeasurements are commonly expressed in microns, also known as micromillimeters, one thousand of which equal one millimeter ($1000\mu = 1$ mm. or $1\mu = 0.001$ mm.). In the foregoing example 0.125 mm. $= 125\mu$.

Determination of Magnification.—The stage micrometer can also be used to determine (with sufficient accuracy for practical purposes) the magnification secured by means of a given objective and eyepiece. This may be accomplished in several ways, but the following are the most convenient:

First Method. Measure the diameter of the field (the illuminated circle seen in the microscope) by means of a stage micrometer. Look with the left eye in the microscope and with the right on a piece of paper raised to the same height as the stage. Make two marks on the paper showing the end points of a diameter of the apparent field. Measure this diameter and divide by the diameter of the actual field, thus obtaining the magnification.

Second Method. Observe the stage micrometer with the left eye and with the right draw on the paper, at the height of the stage, several divisions of the apparent scale. Measure the total width of these divisions and divide by the actual width.

The **Abbé Substage Condenser** (Fig. 20), although not a necessity, is of great value in securing adequate illumination, especially on dark days and when high-power objectives are employed. It consists of a series of two or three lenses (not achromatic), the upper one of which is plano-convex, suitably mounted in brass. The condenser is attached to the substage above the diaphragm and gives the best results when the upper lens is a little below the object and the light is reflected from the plane mirror.

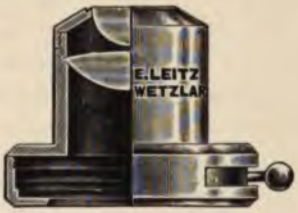


FIG. 20. Abbé Substage Condenser. (LEITZ.)

Polarization Apparatus.—It is often desirable to examine organic tissues and cell contents, as well as inorganic objects, in polarized light for the purpose of bringing out certain physical and chemical properties and characteristic details of structure which are evident in no other way. The polarizing apparatus consists of two Nicol prisms. One, the **Polarizer** (Fig. 21), is mounted in the substage, the other, the **Analyzer**, in the tube or above the eyepiece. A Nicol prism consists of two wedge-shaped pieces of Iceland spar cemented together with Canada balsam (Fig. 21, right). A ray of ordinary light on entering the lower wedge is separated into the ordinary and the extraordinary rays; the former is totally reflected by the balsam and is lost, while the latter passes through the upper wedge. The ray which emerges is polarized and differs from an ordinary ray in that the vibrations are not in all directions perpendicular to the line of projection but are parallel to a plane passing through that line. By means of the analyzer the peculiar properties of the polarized light are brought out. If both the analyzer and the polarizer are in such a position that the diagonal surfaces, cemented with balsam, are parallel, the polarized light from the polarizer is not altered by the analyzer and appears to be the same as ordinary light; if, however, either prism is revolved, the light diminishes in intensity and is entirely extinguished at a position 90° from the first. If a doubly refractive body is placed between the crossed prisms, it appears luminous and displays interference colors, provided the ray of light does not pass through the optical axis of the body (hexagonal and tetragonal crystals), or one of the two optical axes (rhombohedral, monoclinic, and triclinic crystals), in which case the body behaves like a singly refractive body (such as a tesseral crystal or an amorphous substance) and remains dark. Striking polarization phenomena are obtained with starch grains, many vegetable fibers,[1] stone cells, silk, etc., all of which phenomena are described on subsesequent pages.

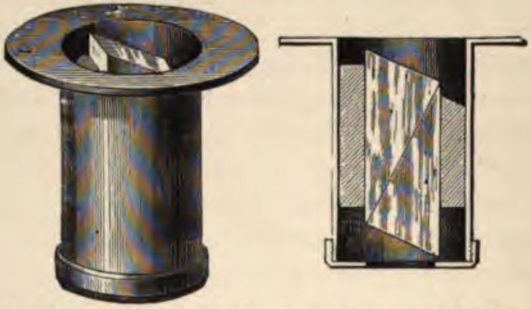


FIG. 21. Polarizer, Entire and in Section, Showing Nicol Prism. (ZEISS.)

Mechanical Stage (see Fig. 14).—This accessory, which may be attached to an ordinary stage by screws or clamps, is chiefly valuable in examining systematically every portion of a mount. The slide is held firmly in a frame which is moved in two directions at right angles to each other by rack and pinion devices operated by milled heads.

---

[1] See BEHRENS: Anleitung zur mikrochemischen Analyse der wichtigsten organischen Verbindungen. Hamburg, 1896. 9.

Camera Lucida.—This apparatus is a great aid in drawing. In some forms the image of the object is superimposed on the drawing-paper, in others the pencil point is reflected so that it appears to be over the image. For accurately tracing the details of an object, it is necessary not only that the image be accurate and distinct, but also that the light is not greatly diminished. The following description by Dippel of an older form of the Abbé camera lucida (Fig. 22) illustrates well the principles involved: "The collar of the apparatus is attached to the upper end of the tube of the microscope by means of the thumb screw at the left and is centered by means of two other screws. The glass cube *W* consists of two prisms cemented together, the diagonal surface of contact being silvered except for a small hole in the middle.

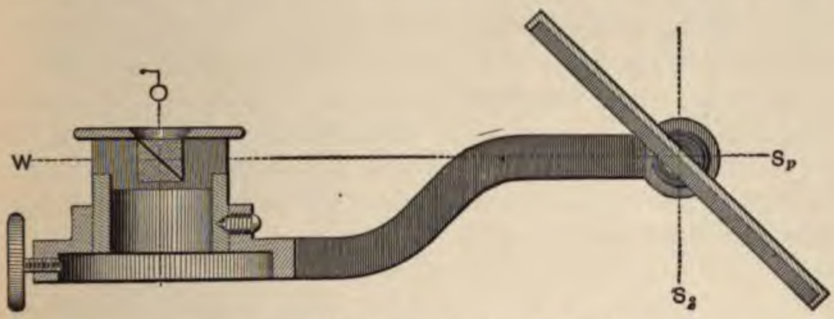


Fig. 22. Abbé Camera Lucida. (Zeiss.)

The mirror *Sp* is borne on an arm so that its central point is 70 mm. from the center of the microscope in a horizontal line. The glass cube is so adjusted that the image, on emerging from the ocular, passes unobstructed through the small hole in the silvered surface and enters the eye (at *O*), while the image of the drawing-pencil is reflected by the mirror through a hole in the brass mounting to the silvered surface, where it is again reflected and likewise enters the eye. The mirror can be turned so that the drawing may be placed in the desired position on the paper." By means of two removable smoked glasses placed between the mirror and the glass cube the lighting of the drawing surface may be tempered to correspond with that of the image. In the more recent forms of the apparatus improved devices for regulating the amount of light and for centering have been introduced.

Microtome.—This apparatus is indispensable in certain lines of investigation, especially when a series of sections of imbedded material is desired. Several different types are on the market, some with fixed knife and movable object, others with fixed object and movable knife. By means of a micrometer screw the object or knife, after each stroke, is automatically raised or, in the case of certain vertical forms, moved forward in readiness for the next stroke. The apparatus can be set to cut sections of any desired thickness down to 1 μ, although it is seldom practicable to go below 5 μ.

Miscellaneous Apparatus.—A razor, flat on one side and concave on the other, is employed in cutting free-hand sections. Scalpels, forceps, needle holders with interchangeable needles of various forms, a hand vice for holding hard objects during sectioning, camel's-hair brushes, watch glasses, etc., may be obtained of any dealer in microscopic supplies. Of especial importance are the slides and cover glasses. The slides should be of white glass free from bubbles. They may be obtained of the ordinary thickness or extra thin, the latter being preferable for permanent mounts. The standard size in England and the United States is 76×26 mm. or 3×1 in. Cover glasses are made of thin glass and are designated No. 1, No. 2, and No. 3 according to the thickness. They are round, square, or rectangular. For ordinary use No. 2 ¾-inch circles are recommended.

CHAPTER III.

MICRO-TECHNIQUE—REAGENTS.

SOME materials are of such a nature that they may be mounted directly, for microscopic examination, in a medium of suitable refractive power (water, glycerine, oil, etc.[1]), while others must first be subjected to a more or less complicated process of preparation. To the former class belong starch, loose fibers (e.g., cotton), yeast cells, and diatoms. These are especially useful as practice materials for the beginner, who by experience must master the art of seeing in the microscope and interpretating his observations.

By far the greater number of raw materials can not be examined directly. Even if the object is thin enough for mounting, it may not be translucent enough to permit the passage through it of light reflected from the mirror beneath, in which case it must be cleared by treatment with reagents with or without the aid of heat. Clearing may usually be effected by boiling in water, soaking in alkali or chloral hydrate, or else warming with dilute acid. Certain objects are best cleared by soaking in an essential oil. Treatment with Schulze's macerating solution (nitric acid and potassium chlorate) removes the dark coloring matter from fruit and seed coats and at the same time isolates the individual cells. Javelle water (chlorinated potash) and Labarraque solution (chlorinated soda) are excellent clearing agents less energetic than the last and therefore better suited for treatment of delicate tissues.[2]

But it is not always the opacity of an object that renders it unfit for examination. Often the tissues are so shrivelled that the contour of the elements is indistinct, or one tissue is so firmly attached to another that the structure of each is obscured. In these cases also reagents play an important part in preparing the material for examination, the particular reagent adapted for each material and the method of procedure being best determined by experience.

---

[1] Usually objects are examined in a liquid medium; only in exceptional cases, as, for example, in studying the cuticular coat of cotton fiber, are objects examined dry.

[2] The seed coat of *Amomum Meleguetta* is an excellent example of a material for which this treatment is adapted.

Thin sections are essential for studying bulky objects such as seeds, fruits, barks, woods, nut shells, ivory, etc. If the object is not too hard it may be sectioned with a razor or a microtome. Excellent sections of woods can be prepared with a hand section cutter and a strong razor or section knife. Sections of very hard materials such as nut shells and teeth are prepared by grinding on a stone. A thick section cut with a saw is first attached to a cork by means of hot Canada balsam and ground as thin as possible on a grindstone. It is then removed from the cork and rubbed back and forth with the finger on a Belgian razor hone until it is sufficiently translucent.

In examining a material it is important at the outset to have clearly in mind what is the purpose of the work, that is, what questions are to be answered. As a rule the first question concerns the structure of the material and involves a study of the nature and arrangement of the tissues as well as the form and size of the cell elements. The second question involves usually a study of the cell contents. A practical example will make clearer the procedure necessary in such an investigation. An economic bark (e.g., oak bark) has a somewhat complicated structure; furthermore some of the tissues are much shrivelled and others are rich in contents, so that a section examined in water appears very indistinct. If it is warmed gently in dilute potash or soaked for some time in chloral hydrate the tissues are rendered much more distinct. This treatment however destroys or dissolves certain of the substances contained in the cells. It is therefore necessary to carry on a parallel investigation with different reagents to determine the nature of the cell contents. Other instructive examples of materials requiring varied treatment are leguminous seeds, nutmeg, cocoa bean, etc.

Of great importance is the use of dyes and reagents for producing color reactions. The use of color reactions dates back to the early investigations in histology, but those first employed were limited chiefly to the detection of starch, proteids, tannin, and lignin. More recently there have come into use numerous dyes with specific tinctorial power for certain tissues and cell contents which render them of especial value in diagnosis.[1]

---

[1] BEHRENS: Hilfsbuch z. Ausführung mikr. Untersuchungen.

Reagents.

The following list of the most important reagents and dyes is given by A. TSCHIRCH.[1]

I. ACIDS:

1. *Sulphuric Acid*, concentrated and dilute. Dissolves cellulose, starch, and aleurone grains; forms calcium sulphate with calcium oxalate. Iodine and sulphuric acid color cellulose blue. Protoplasm saturated with sucrose gives with sulphuric acid a rose color.
2. *Hydrochloric Acid*, concentrated and dilute. Swells cell walls composed of cellulose; acts as a clearing agent.
3. *Nitric Acid.* With potassium chlorate forms Schultze's macerating liquid.
4. *Chromic Acid.* Reagent for cork, which it does not dissolve; clearing agent; renders rings of starch grains more distinct.
5. *Acetic Acid.*
6. *Picric Acid.* Hardening reagent.

II. ALKALIES:

7. *Potassium Hydrate*, 5 per cent solution, diluted if necessary. Used for clearing and swelling cell walls, also for expanding collapsed cells.
8. *Ammonia Water.* Clearing and bleaching agent.
9. *Javelle Water* (chlorinated potash) and *Labarraque Solution* (chlorinated soda). Bleaching reagents. Thoroughly triturate 75 grams of fresh chlorinated lime (bleaching powder) with 600 cc. of water added in two or three successive portions and filter. To the filtrate add a solution of 58 grams of crystallized potassium carbonate (for Labarraque solution, 150 g. of sodium carbonate) in 400 cc. of water, mix thoroughly, warm if the solution gelatinizes, and again filter. The solutions gradually lose strength on standing, and should be kept in stoppered bottles in a cool, dark place.

---

[1] Angewandte Pflanzenanatomie. Wien, 1889, 24.

III. REAGENTS FOR SPECIFIC REACTIONS:

10. *Iodine Solutions:* (1) Aqueous solution; (2) in potassium iodide (potassium iodide 0.2 gram, iodine 0.05 gram, and water 15 cc.). Color starch blue, proteids yellow brown, cell walls yellow.

11. *Iodine Glycerine*, saturated solution of iodine in glycerine.

12. *Iodine Tincture.*

13. *Chlorzinc Iodine.* Colors cellulose blue, lignin, suberin, and cutin yellow. Treat an excess of zinc with hydrochloric acid, evaporate to a specific gravity of 1.8, and filter through asbestos. As needed, saturate a small portion of the sirupy liquid first with potassium iodide and finally with iodine.

    The solution may also be prepared by dissolving 30 grams of zinc chloride, 5 grams of potassium iodide, and 0.89 gram of iodine in 14 cc. of water. A crystal of iodine should be kept in the bottle to prevent deterioration.

14. *Potassium Bichromate*, saturated solution. Reagent for tannin.

15. *Ferric Chloride*, 33⅓ per cent solution. Imparts a blue or green color to tannin substances.

16. *Copper Sulphate* (and potassium hydrate). Reagent for sugars. The section is soaked 1 to 2 minutes in copper sulphate solution, washed, and placed in boiling dilute solution of potassium hydrate. Dextrose and invert sugar form a red precipitate of copper suboxid; sucrose forms no precipitate.

17. *Cuprammonia.* Dissolves cellulose. Precipitate cupric oxyhydrate from a solution of copper sulphate by adding a slight excess of caustic soda or ammonia, filter, and thoroughly wash. Dissolve the moist precipitate in strong ammonia with the aid of heat, cool, and filter from the precipitate which forms.

    A simpler method of preparation is to allow ammonia water to act on copper filings for 24 hours and then dilute with more ammonia water.

    The solution should be freshly prepared and kept in he dark.

rcuric Chloride. Hardens aleurone grains.

illon's Reagent. Proteids form with this reagent, on heating, a reddish precipitate. Dissolve metallic mercury in an equal weight of concentrated nitric acid and dilute with an equal volume of water. The solution should be freshly prepared.

20. *Aniline Sulphate.* Colors lignified tissues lemon yellow.
21. *Phloroglucin.* With hydrochloric acid colors lignified tissues cherry red.
22. *Alcohol.* Solvent for resins, essential oils, and some fatty oils; hardening material.
23. *Ether.* Solvent for resins, fats, etc.

IV. DYES:

Fuchsin, Methyl Violet, Methyl Green, Nigrosin, Aniline Brown, Naphthylene Blue, Congo Red, Methylene Blue, Hæmatoxylin, Corallin, Cochineal, Carmine, Alkanna Tincture, etc. On soaking for some hours in alkanna tincture, fatty and essential oils, also resins, are colored red.

CHAPTER I.

STARCH [1]. INULIN.

GENERAL CHARACTERS. POTATO STARCH.

PURE starch is a white powder consisting of grains of different size and form. In commerce it also appears in the form of short rods, angular lumps, and various shaped fragments, all of which are readily reduced to a powder.

Potato starch is particularly suited for studying the general morphological characters which are common to all starches. To the naked eye this starch appears as a white, glittering powder in which, after spreading out on the slide, may be seen large individual grains.

Forms.—A very small quantity, such as may be held on the broad side of a lancet needle, is placed on a slide, carefully mixed with a drop of water, and covered with a cover glass, taking care not to exert any pressure, since this is liable to injure the grains. A few air bubbles are not detrimental.

With a magnification of about 200 diameters may be seen numerous colorless bodies of different size and form, which display a series of rings or lamellæ (Fig. 23). If, by means of the fine adjustment, the distance of the lower lens of the objective from the object is increased, the structure appears less distinct and the contour somewhat contracted, thus showing that these bodies are rounded, not flat and disc-shaped. Although the large grains are irregular and exceedingly variable in form, we note that there is a preponderance of ovoid, irregularly ovate, rounded triangular, quadrangular, and oyster-shaped forms. Viewed on edge these large grains are mostly elliptical in outline. Here and there are grains united to form twins and triplets.

---

[1] Greenish: Foods and Drugs. London, 1910. T. F. Hanausek: Die Nahrungs- und Genussmittel. Cassel, 1884. v. Höhnel: Die Stärke und die Mahlproducte. Cassel, 1882. Leach: Food Inspection and Analysis. New York, 1914. Moeller: Mikroskopie der Nahrungs- und Genussmittel. Berlin, 1905. Tschirch: Angewandte Pflanzenanatomie. Wien, 1889. Villiers et Collin: Traité des altérations et falsifications des substances alimentaires. Paris, 1900. Winton: Microscopy of Vegetable Foods. New York, 1915. Wiesner: Rohstoffe. Leipzig, 2. Aufl. 1903.

Size.—Next to the form, the size is of chief interest. On careful observation it is apparent that there is no sharp distinction between large and small grains, or, in other words, there are all sizes from the smallest to the largest grains. This fact is of importance, since in other starches either there is but little difference in the size of the individual grains (e.g., maize, rice) or else the grains are partly large and partly small without any appreciable number of middle-sized grains (e.g., wheat, rye, barley).

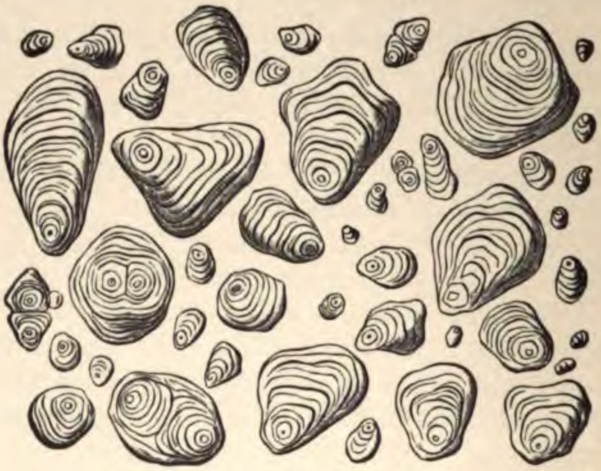


FIG. 23. Potato Starch. (TSCHIRCH.)

The usual length of the large grains of potato starch is 50–80μ, although the maximum is 100μ.[1] The breadth and thickness are usually less than the length, being respectively 30–60μ and 20–30μ.

It should be remembered that these measurements are not of the dry grains, but of the grains mounted in water, in which medium they swell to an appreciable extent. This swelling can be avoided by mounting in anhydrous glycerine, but accurate measurements in this medium are not practicable since the starch grains, having about the same index of refraction as the glycerine, are scarcely visible. More accurate results may be secured by measuring the grains in oil; however, it has always been customary to measure starch grains in water and tacitly ignore the error due to swelling.

---

[1] T. F. HANAUSEK: Nahrungs- und Genussmittel. Cassel, 1884, 107.

Rings.—The structural details visible in a well-formed grain consist of a series of eccentric rings arranged about a hilum situated usually in the smaller end. Rings are scarcely visible on a normal grain of wheat starch. In order to comprehend the origin and significance of these rings, we must consider the most important steps in the process of formation of starch in the plant.

FORMATION OF STARCH.

Starch is formed in the green organs, notably the leaves and stems. The general anatomical structure of a leaf, as may be studied in cross-section (Fig. 24), is as follows: Two epidermal layers (*e*), one on the upper, the other on the lower side, cover the middle tissues consisting of mesophyl, and the vascular system forming the veins or nerves. The mesophyl performs two physiological functions: (1) it permits the free exchange of gases with the outer air, and (2) it carries on the process of formation of organic matter, known as assimilation or photosynthesis. In very many cases there are two distinct tissues corresponding to these two functions, one the spongy parenchyma (*sch*), the other the palisade parenchyma (*p*). The arrangement of these two tissues may be **Isolateral,** that is with palisade parenchyma on both sides of the leaf with spongy parenchyma between, or **Bifacial,** that is with palisade parenchyma on the upper and spongy parenchyma on the lower side, or (less often) **Centric,** that is with only one form of tissue for both physiological processes.[1]

In the bifacial leaf shown in Fig. 24, the palisade cells (*p*), underlying the epidermis (*e*), are seen to contain numerous green granules known as **Chlorophyl Grains** or **Chloroplasts.** These chlorophyl grains taken together form the laboratory in which is carried out the most marvellous chemical process found in nature. Here the carbonic acid from the air [2] and the water pumped up by the roots from the soil meet and, by means of the energy of light, form organic matter. This process is known as **Assimilation** or **Photosynthesis.** It is not certainly known what is the first product produced in the chlorophyl grains; it may be a simple carbon compound, possibly, as suggested by some investigators, formaldehyde (CH·OH), although if this is formed it must be immediately transformed into other substances since it is a very active protoplasmic poison.

---

[1] TSCHIRCH: Angewandte Pflanzenanatomie, 317.

[2] Air contains 0.03–0.04 per cent of carbonic acid.

The first visible product of the assimilatory process is starch (**Assimilation Starch**). The palisade cells, at their narrow ends, are joined to the so-called funnel cells (Fig. 24, *t*), which act as sucking and accumulating organs. They conduct the starch, which has previously been changed to a soluble substance (probably sugar), into the spongy parenchyma and this in turn conducts it into the vascular system consisting of fibro-vascular bundles (Fig. 24, at the right, above the intercellular

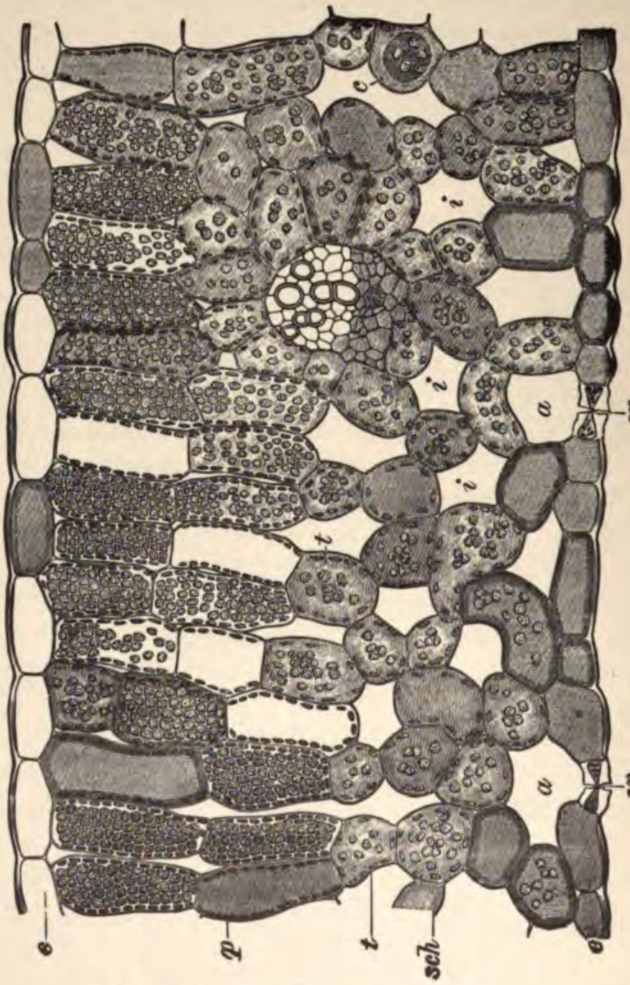


FIG. 24. Cross-section of a Beet Leaf. (TSCHIRCH.)
e epidermis; *sp* stomata; *a* respiratory cavity; *i* intercellular spaces; *p* palisade cells; *t* funnel cells; *sch* spongy parenchyma.

space *i*). In each cell into which the soluble substance enters, it is deposited again as starch, which in turn is dissolved so as to enter the next cell. The starch formed in this translocation is called **Transitory Starch.** The fibro-vascular bundles conduct the dissolved starch to parts where it is needed for building up new organs or parts of organs, or, if there is a surplus, to special magazines, where it is stored up for future use. In these magazines are peculiar colorless bodies known as **Leucoplasts,**[1] similar to chlorophyl grains or chloroplasts, which are instrumental in forming from the mother liquid the starch grains. Starch thus deposited is termed **Reserve Starch** and is the only form utilized for the manufacture of commercial starch. Among the magazines in which it is stored are rhizomes, tubers, stems (bark and medullary rays), fruits, and seeds. Fig. 25, *D*, shows a grain of wheat in longitudinal section. The germ (*e*) is situated at the base; the remainder of the grain consists largely of the magazine for reserve material, known as the **Endosperm.** In cross-section of the grain (Fig. 26) we see, under the compound microscope, the cells of the endosperm containing (together with proteids, etc.) reserve starch in the form of rounded grains (*st*).

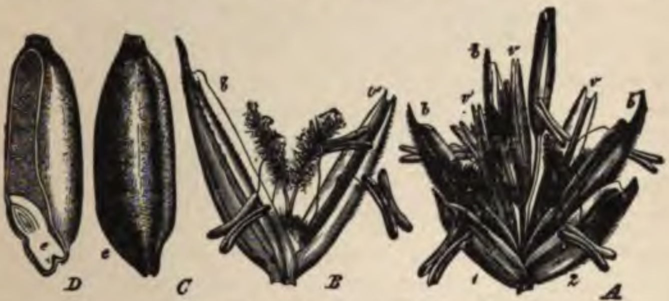


FIG. 25. Wheat. (SCHUMANN.)

A spikelet; *B* single flower; *C* whole fruit; *D* fruit in longitudinal section. *1* and *2* empty glumes; *b* flowering glumes; *v* palets; *e* embryo.

Starch grains are formed in magazines of this nature by the successive deposition of layers. According to SCHIMPER[2] and ARTHUR MEYER,[3] it is probable that each layer is made up of radiating, crystalline fibers (trichites), and consequently the starch grain should be regarded as a

---

[1] A. F. W. SCHIMPER: Untersuchungen über die Entstehung der Stärkekörner. Bot. Ztg. 1880, 881.

[2] Bot. Ztg. 1881, 185.

[3] Untersuchungen über die Stärkekörner. Wesen. und Lebensgeschichte der Stärkekörner der höheren Pflanzen. Jena, 1895, 116

Sphærite or **Sphæro-crystal**, analogous to the mineral hematite. Examined in the micro-polariscope with crossed Nicols, a grain of potato starch, like a doubly refractive crystal, is conspicuous in the dark field as a brilliantly illuminated object marked by a dark cross the bars of which intersect at the hilum.

The rings of starch grains vary in boldness and distinctness; some are quite pronounced, while others appear as delicate markings. Their distinctness is generally believed to be dependent on the variation in the water content of the different layers, the hilum containing the greatest amount of water and the successive layers alternately greater or less amounts. At the beginning of the formation of a layer the mother liquid is relatively concentrated, but it becomes more and more dilute as the deposition continues and the layers become richer and richer in water, until finally the deposition ceases, to be begun again when the mother liquid reaches the necessary degree of concentration.[1]

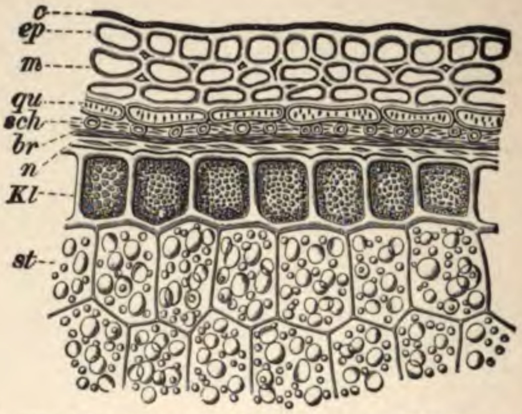


FIG. 26. Cross-section of the Peripheral Layers of Wheat. (TSCHIRCH.)
ep epicarp with *c* cuticle; *m* mesocarp or middle layer; *qu* cross cells; *sch* tube cells; *br* spermoderm; *n* perisperm; *Kl* aleurone layer; *st* starchy endosperm.

---

[1] ARTHUR MEYER (*loc. cit.*, 129) explains this phenomenon as follows: "Starch grains grow like the sphæro-crystals of other carbohydrates, and their layers, like those of other sphæro-crystals, owe their origin to the fact that the concentration of the mother liquor, which determines the form of the trichite, periodically changes." H. FISCHER has shown, however, that this periodic change is not connected with the changes in growth dependent on the transition from day to night. (Bot. Centbl. 1902, **90**, 232.) MEYER assumes that each starch grain is completely and continually enveloped by the substance of its chromatophore (leucoplast or chloroplast), but that this envelope, on account of its extraordinarily small thickness (in *Adoxa* not over 0.000002 mm. = 0.002 μ), usually must remain invisible.

CHEMICAL PROPERTIES OF STARCH.

The starch of commerce is insoluble in water, alcohol, ether, chloroform, benzene, and cuprammonia. So-called "green starch," as obtained in the process of manufacture, contains about 45 per cent of water; the air-dry product 12–20 per cent or more. Anhydrous starch has the formula $C_{12}H_{20}O_{10}$, or $C_{18}H_{30}O_{15}$, or $C_{36}H_{62}O_{31}$. LIEBIG, in 1834, gave the formula for starch as $C_6H_{10}O_5$. C. NÄGELI[1] found that it consisted of two substances. If potato starch is treated with saliva at a temperature of 40–55°, a substance dissolves which NÄGELI called **Granulose**, while the residual skeleton, according to that author, is pure cellulose. This **Starch Cellulose** (the farinose of MOHL) forms but a very small percentage[2] of the starch grain, the bulk consisting of granulose. According to ARTHUR MEYER, starch consists of a substance designated by him **Amylose**, and small amounts of a decomposition product of the same, **Amylodextrin.** Amylose exists as two modifications, one (β-amylose) becoming fluid in water at 100° C., the other (α-amylose) not becoming fluid in water at that temperature.

Gelatinization.—Since starch has a greater specific gravity than water it soon settles to the bottom in cold water, a fact taken advantage of in the manufacture of commercial starch. If, however, it is heated with water to 45–55° C., the individual grains begin to swell and, as the temperature rises, they gradually lose their shape, until finally the mixture is converted into a uniform paste. The exact temperatures at which these changes begin and end are different for the different kinds of starch. The gelatinization temperatures for the common starches, as given by LIPPMAN, are as follows:

Kind of Starch.	Swelling Begins, Degrees C.	Gelatinization Begins, Degrees C.	Complete Gelatinization, Degrees C.
Rye	45	50	55
Horse chestnut	52.5	56.2	58.7
Rice	53·7	58.7	61.2
Barley	37·5	57·5	62.5
Potato	46.2	58.7	62.5
Maize	50	55	62.5
Wheat	50	65	67·5
Tapioca	——	62.5	68.7
Arrowroot (*Maranta arundinacea*)	66.2	66.2	70
Sago (*Sagus Rumphii*)	——	66.2	70
Buckwheat	55	68.7	71.2
Acorn	57·5	77·5	87·5

---

[1] Die Stärkekörner. Zürich, 1858, 209.

[2] See TSCHIRCH: Amylum. Realenzyklopädie d. ges. Pharm. 2. Aufl. 1904, **1**, 583. WIESNER: Rohstoffe. 2. Aufl., **1**, 550.

From this table it is evident that some of the starches can be distinguished from each other by their gelatinization temperatures, although in the case of mixtures this is difficult. WITMACK[1] bases on this principle a method for detecting an admixture of wheat flour in rye flour and *vice versa.* WEINWURM[2] has proposed taking advantage of the temperature of gelatinization as a means of quantitatively determining wheat flour in rye flour. He found that by digesting at 62½–63° with water for one hour almost all the starch grains of rye flour were swollen or gelatinized, but the starch grains of wheat flour, although somewhat swollen, still showed distinct dark outlines. By counting the grains the amount of admixture may be determined within about 5 per cent.

Gelatinization of starch is also brought about by numerous chemicals such as potassium and sodium hydrate, zinc chloride, magnesium chloride, chloral hydrate,[3] etc. In any case gelatinization is not a true solution of the starch, much less a chemical change.

Paste made from potato starch is very different from that made, for example, from wheat starch. It is stiff and is not directly applicable for sizing or finishing fabrics. BELLMAS[4] has devised a process of treatment of potato starch by warming at 55° with addition of 2 per cent sulphuric acid, thus converting it into a water-soluble form which gives a clear solution on boiling with water. This solution is particularly adapted for sizing, since it penetrates the threads and uniformly stiffens the fabrics.

Iodine Reaction.—The oldest and most important reagent for starch is iodine. If starch is mounted in an alcoholic solution of iodine, no characteristic reaction takes place, the grains being colored brown. If, however, the iodine acts on the starch in conjunction with water, the grains are colored blue. As a rule iodine dissolved in water containing potassium iodide is employed, although the alcoholic solution added to a water mount also gives the characteristic blue color. With the exception of certain special kinds of starch, described further on, all starches give the characteristic reaction with iodine, although the color varies according to the kind of starch and the preparation of the reagent, being in some cases blue, in others blue violet, and in others still red violet. The color is immediately discharged by adding ammonia or potash.[1]

---

[1] Anleitung zur Erkennung organischer und unorganischer Beimengungen im Roggen- und Weizenmehl. Leipzig, 1884, 36; also article on Flour (Mehl) in Dammer's Lexikon der Verfälschungen. Leipzig. 1887, 548.

[2] Ueber die qualitative und quantitative Bestimmung von Weizenmehl im Roggenmehl. Ztschr. Unters. Nahr. Genussm. 1898, 98.

[3] See A. MEYER: *loc. cit.*, 20.

[4] VIERNEISEL: Zur Herstellung löslicher Kartoffelstärke nach dem Verfahren Bellmas. Österr. Chem. Ztg. 1902, 366.

According to recent theories, the absorption of iodine by starch is possible only through the agency of small amounts of hydriodic acid or an iodide. Starch colored blue, the so-called iodized starch, is, however, no chemical compound of iodine with starch, neither is it a simple mechanical mixture, but, according to MEYER,[2] a solution of iodine or potassium iodide in the starch.

A derivative of starch, known as **Amylodextrin**, occurs in normal grains of the common sorts of starch, and especially in certain abnormal grains found in a number of plants. The grains of certain varieties of sorghum, rice, and millet are colored red,[3] not blue, by iodine. They are made up largely of amylodextrin and are very different from true starch grains. Grains of amylodextrin also occur in other plants, a notable example being the curious bodies found in mace to which TSCHIRCH[4] has given the name **Amylodextrin Starch.** Amylodextrin, like dextrine, dextrose, etc., is probably formed by the action of ferments and dilute acids on starch, and, according to A. MEYER,[5] is distinguished from true starch (amylose) by the following reactions:

	AMYLOSE.	AMYLODEXTRIN.
Basic lead acetate	Precipitate in 0.05% solution	No precipitate in 6% solution.
Tannin solution	Precipitate in 0.005% solution.	No precipitate in cold 5% solution.
Iodine	Colors dilute solution true blue.	Colors dilute solution true red.
Fehling solution	No reduction	100 grams amylodextrin gives same reduction as 5.6 grams anhydrous dextrose.
$[\alpha]_D$ in calcium nitrate solution	+230°	+150°

Another important derivative of starch is **Dextrine.** If dry starch is heated at a rather high temperature, there is obtained a brown mass which, when mixed with water, has marked adhesive properties; this consists largely of dextrine. The same substance is also formed as an intermediate product by heating with dilute acids, such as hydrochloric, sulphuric, nitric, and oxalic acids, or by the action of diastase.

---

[1] For further details see MEINECKE: Studien über die Jodstärke-Reaction. Chem. Ztg. 1894, 18, 157.

[2] *Loc. cit.*, 26.

[3] See A. GRIS: Ann. sci. nat. bot. 1860, 7, 896; DAFERT: Ber. Deutsch. Bot. Gesell. 1887, 108; ARTHUR MEYER: *loc. cit.*, 80, and Ber. Deutsch. Bot. Gesell. 1886, 337. MITLACHER: Ztschr. allg. Österr. apoth. Ver. 1901, 813.

[4] TSCHIRCH u. OESTERLE: Anatomischer Atlas, 252.

[5] *Loc. cit.*, 29.

The final product of this last-named process is some form of sugar. By heating with dilute acids, dextrose or fruit sugar is obtained.[1] Similar changes are brought about by enzymes which appear during the sprouting of starchy seeds, especially the cereal grains. In sprouting barley there is formed **Diastase**, which converts a part of the starch into **Maltose**, also **Glucase**, which converts another part into **Dextrose.**

The brewing and distilling industries, also the digestion of starch in the animal body, are dependent on the action of enzymes.

Potato starch[2] is obtained in two ways: (1) by grinding the tubers, washing with water, allowing the starch to settle, and purifying the crude product; (2) by the so-called Völcker process, in which the potatoes are first sliced and the slices subjected to a fermentation process in heaps. Often the starch is mixed with a small amount of ultramarine to counteract the yellowish color. It gives off an odor resembling that of sauerkraut, especially when in a moist condition, or on roasting or treating with sulphuric acid. Paste made from potato starch is conspicuously transparent, that made from rice or wheat starch is milky.

According to v. HÖHNEL,[3] the grains of pure potato starch are visible to the naked eye, those of wheat, rye, and barley starch are visible under a lens, while the grains of rice starch, owing to their minute size, can not be seen even with the aid of a lens.

For use in the arts, potato starch must conform to the description already given. It is readily converted into dextrine and sugar and is much employed as a size for fabrics, both in the mill and the laundry, for the manufacture of paste, for the preparation of foods (imitation sago, inferior macaroni, etc.), as a size and whitening material in paper manufacture, and finally as an adulterant of other starches and various powdered foods. In metal foundries potato starch is sometimes used in place of powdered charcoal or graphite for dusting over the moulds. The chief consumption of this starch in Europe is, however, for the manufacture of sugar and alcohol. The residues from the manufacture of potato starch, consisting of pulp and "starch fiber", are utilized as a fodder, and as a filler in the manufacture of inferior wrapping paper.

---

[1] Commercial glucose is a mixture of dextrose with dextrines, maltose, etc.

[2] REHWALD: Stärkefabrication. Wien, 2. Aufl. 1885. L. v. WAGNER: Handbuch der Stärkefabrication. Weimar, 2. Aufl 1884.

[3] Die Stärke und die Mahlproducte. Cassel, 1882, 68.

A Case of Abnormal Potato Starch.—A sample submitted for examination by a manufacturer was stated to be unfit for making dextrine. On examination under the microscope it was noted that many of the starch grains had undergone important changes. Some of the grains were marked by clefts and fissures which passed through, or radiated from, the hilum, others had an irregular sac-like nucleus, and others still were finely pitted or corroded, displaying cavities, channels, etc. Fig. 27 shows the leading forms of corroded and partially dissolved grains found in this sample. The grains had doubtless been acted on by a solvent ferment (diastase), the phenomena being such as may be observed in a sprouting potato. It is probable this starch had been made in the spring from potatoes which, owing to storage in a cellar, had begun to sprout.[1]

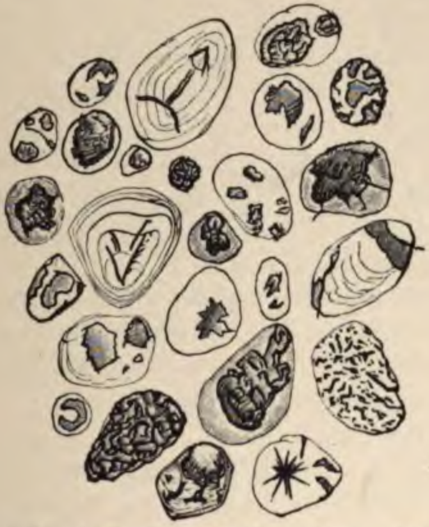


Fig. 27. Potato Starch, Partially Dissolved. ×300. (T. F. Hanausek.)

---

[1] According to A. Meyer (*loc. cit.*, Table III, X, Y), similar phenomena are evident in the starch grains of *Dieffenbachia Seguina* Schott after treatment for three weeks with diastase. The same author states that such corrosion forms should appear only in those grains of potato starch which previously had clefts or fissures; the perfect grains dissolve in layers, leaving numerous narrow, almost spindle-shaped grains.

WHEAT STARCH. (Fig. 28.)

Wheat, rye, and barley starches are of one and the same type The grains are of two kinds; the large and the small.

The large grains of wheat starch are thick, lenticular, appearing i surface view disc-shaped, usually without evident rings or hilum, le often with indistinct rings, or with clefts radiating from the center. See

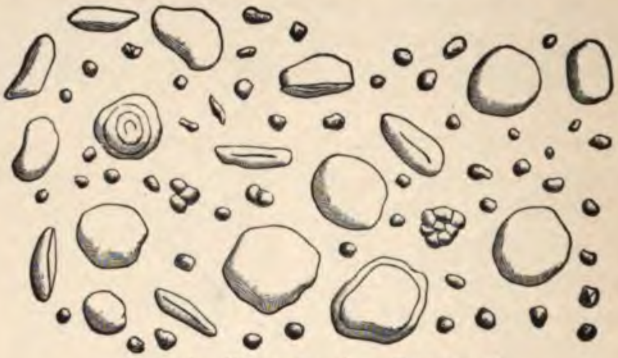


FIG. 28. Wheat Starch. (TSCHIRCH.)

on edge, they are elliptical in outline, often with a central cleft what appears to be a cleft. The size of these large grains varies fro 15 to 45μ, although most of the grains are 20–35μ. In starch treated wi dilute chromic acid, or that from sprouted grain, a central hilum a delicate rings are visible.

The small grains are mostly globular, ovoid, pointed ovoid, a measure 1–8μ; they also occur in twins and triplets, the individuals which, when isolated, have one or two plane surfaces. Often on a lar grain may be seen the impression of small grains which at one time we in contact with it, forming reticulated markings.

RYE STARCH is quite similar to wheat starch except that the lar grains are mostly larger and very often have at the center crossed radiating clefts formed during drying. The maximum size observ by the writer is 52μ; most of the grains, however, measure 35–45μ.

The large grains of **BARLEY STARCH**, on the other hand, a

---

[1] TSCHIRCH (Arch. Pharm. 1883 and 1884), in pointing out the characters of aid diagnosis, distinguishes between the *typical forms* and the *common forms*, the former be those which are characteristic, the latter those which occur in greatest numbers. T typical forms are the common forms in potato, wheat, and most other starches; less of the typical forms occur in smaller numbers, as, for example, the spindle-shaped gra of oats.

smaller than those of wheat; the maximum size is 35μ, but most of the grains are about 20μ. Often the grains are not exactly round but are elliptical or reniform in outline.

Neither rye nor barley starch is manufactured on a large scale. The processes employed in the manufacture of wheat starch are here considered only so far as they affect the appearance of the grains. Wheat starch can be made from the whole grain, from the coarsely ground grain, or from the flour; in the two former cases the whole or coarsely ground grain softened in water and triturated. The chief object to be attained is a separation from the gluten, for which two methods are employed.

The **Halle Process**, the one in most common use, depends on an acid fermentation process which dissolves the gluten. The mash, obtained by soaking the whole or coarsely ground grain in water and triturating, is mixed with an acid solution obtained from a previous run and subjected to fermentation dependent chiefly on the presence of lactic bacteria. As soon as the gluten is in large part dissolved, the crude starch is separated by washing drums and purified by settling or centrifuging. Pure white starch is obtained by this method only in summer. Although the method yields the purest product, it wastes the valuable gluten and, for this reason, is far from ideal.

The **Alsation Process** does not utilize fermentation, or at most only a weak and partial fermentation. The water in which the wheat is soaked is frequently changed to retard souring. After the grain is softened it is kneaded and the starch removed by washing. The milky liquid is allowed to become slightly acid, and the crude starch and gluten starch are separated by centrifuging. The gluten starch, after drying and grinding, is mixed with flour or sold as gluten meal, while the crude starch is purified in various ways, usually by subjecting it to a short fermentation and centrifuging.

Starch is prepared from flour by either the Martin or Fesca method. In the **Martin Process** the meal is kneaded to a stiff dough, allowed to stand 1–2 hours to permit the gluten to combine with the water, and washed with agitation on a fine sieve. The residue left on the sieve, which still contains a considerable amount of starch, is used for making dough products such as macaroni and noodles. The starch is allowed to settle in vats and is subjected to a weak fermentation process.

By the **Fesca Process** a milky liquid is prepared from the flour, which, by means of a centrifuge, is separated into crude starch and gluten starch.

A Case of Abnormal Wheat Starch.—A sample submitted for examination was stated by the manufacturer to be unsuited for use as a size. Microscopic examination showed that many of the large grains were partially eaten away, mostly on one side, but the appearance was somewhat different from that of a sprouted grain such as described below. Exactly the same appearance was obtained when starch was kept for some days in dilute lactic acid. The conclusion was reached from this evidence that the starch had been prepared by the acid process, and that the treatment with lactic acid was continued beyond the time necessary to dissolve the gluten.

Starch from Sprouted Grain is recognized by the characteristic appearance due to the solvent action of ferments. Wheat starch (Fig. 29) displays delicate concentric rings and more or less distinct central fissures. Often the rings in parts of a grain (in the same radial section) are very distinct, while in intermediate parts they are scarcely evident. After long-continued action of the ferments the grains become hollowed in the center and show numerous canals resembling the burrows of insects.

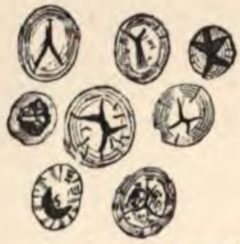


Fig. 29. Starch of Sprouted Wheat. ×300. (T. F. Hanausek.)

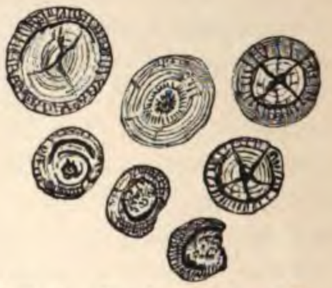


Fig. 30. Starch of Sprouted Rye. ×300. (T. F. Hanausek.)

Starch from sprouted rye (Fig. 30) presents a very different appearance. The outer layers are radially striated and are separated from the inner by a marked circular crack, while the central portion is irregularly fissured, the original clefts about the hilum being enlarged.

In the arts wheat starch is valuable for a great number of purposes; it is used as a size for the preparation of paste—in fact, for all the purposes mentioned under potato starch.

MAIZE STARCH. (Fig. 31.)

Maize starch (corn starch) is obtained by soaking Indian corn in water, triturating, and washing on cylindrical sieves. The starch in the horny endosperm is liberated from the proteid matter by treatment with caustic soda or sulphurous acid, or by a mild fermentation process. The starchy endosperm of the maize kernel (Fig. 32) consists of two distinct portions, each with its distinct type of starch grain. The outer portion is translucent, horny, and consists of closely crowded starch grains cemented together with proteid matter, whereas the inner portion is white and floury and consists of loosely distributed starch grains.

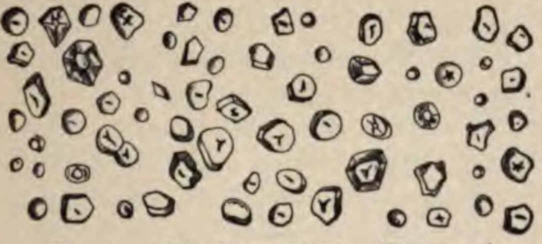


FIG. 31. Maize (Corn) Starch. (TSCHIRCH.)

In the horny endosperm the starch grains are polygonal, sharply angular, often united in groups, commonly with crossed or radiating clefts at the center, never with rings, somewhat uniform in size, being commonly 10–20μ in diameter and never exceeding 30μ. In the floury endosperm the grains are rounded, seldom united, much less uniform in size than the grains of the horny endosperm.

Maize starch is by far the most important commercial starch in the United States. It is employed in large quantities in the arts and for laundry purposes. A specially purified, powdered form, known as corn starch, is used for puddings and other culinary preparations. In Europe maize starch is used under the names mondamin, corn flour, and maizena.[1]

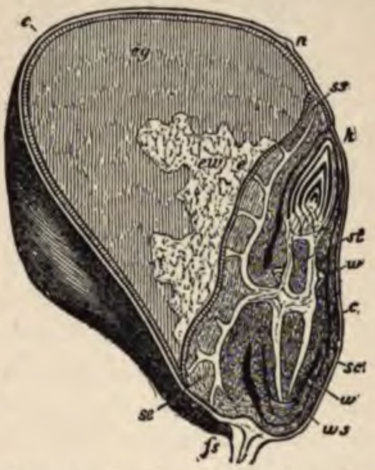


FIG. 32. Longitudinal Section of a Maize Kernel. ×6. (SACHS.)

c pericarp; *n* remains of stigma; *fs* base of kernel; *eg* horny endosperm; *ew* floury endosperm; *sc* and *ss* scutellum of embryo; *e* epithelium of scutellum; *k* plumule; *w* (below) primary root, *ws* root sheath; *w* (above) secondary root; *st* stem.

---

[1] According to WIGAND (Pharmakognosie, p. 33), the starch made from the palm *Corypha cerifera* is also known as maizena.

RICE STARCH. (Fig. 33.)

Owing to the horny nature of the rice kernel it is necessary, in prepa ing rice starch, to employ some solvent for the proteids. As a rule tl grain is treated with dilute caustic soda and then ground. Acids and fe ments are also used to some extent.

Commercial rice starch[1] consists of sharply polygonal crystal-lil grains, of which many, especially those with triangular outline, have sha points. Even in the aggregates (which in the original kernels are elliptic or rounded like those of oats) the contour of the individual grains is ev dent, the surfaces of contact appearing as distinct lines. Perfectly rounde grains are not present even among the smallest forms, a fact of conside able importance as a means of distinction from similar starches. Th grains are 3–10μ, never over 10μ. If the starch is prepared directl from the rice kernel, the maximum size is 8μ, but if alkali or acid is use in its preparation the grains are somewhat larger owing to the action c these chemicals. The individual starch grains of rice, buckwheat,[2] an oats are very similar; oat starch is not, however, prepared commercially.

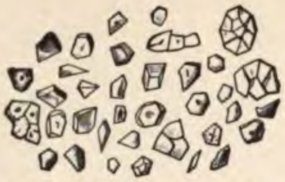


FIG. 33. Rice Starch. ×500. (T. F. HANAUSEK.)

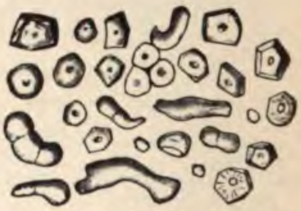


FIG. 34. Buckwheat Starch. ×500. (T. F. HANAUSEK.)

BUCKWHEAT STARCH (Fig. 34) consists of single grains and aggr gates. The larger single grains are rounded polygonal, never tapering t a sharp point; the smaller grains are quite round. They are 8–15μ, usu ally about 10μ. Characteristic are the vermiform, rod-shaped, or clul shaped aggregates, which are usually of irregular thickness, rounded c swollen at the ends, and are often crooked. The individuals in thes aggregates seldom exceed 4, notwithstanding the statement that they var up to 15. Usually the surface of contact is indistinct.

---

[1] See T. F. HANAUSEK: Reis- und Buchweizenstärke, Chem. Ztg. 1894, **18**. TSCHIRC Arch. Pharm., **23**, 528.

[2] TSCHIRCH distinguishes between the horny and floury endosperm of buckwheat an the types of starch grains in each. Arch. Pharm., **23**, 525, and Realenzyklopädie d. ge Pharm. 1. Aufl. 1886, **1**, 338. See also T. F. HANAUSEK: Chem. Ztg. 1894, **18**.

Oat Starch (Fig. 35), like untreated rice starch, is made up in part of rounded or ovoid aggregates, consisting of 2–200 grains, most of which are sharply angular, although some (from the surface) are rounded on one side. The single grains are partly round (the filling grains of Tschirch) and partly various characteristic forms—spindle-shaped, lemon-shaped, crescent-shaped, triangular, etc. They are 5–12 μ in diameter, usually about 7 μ.

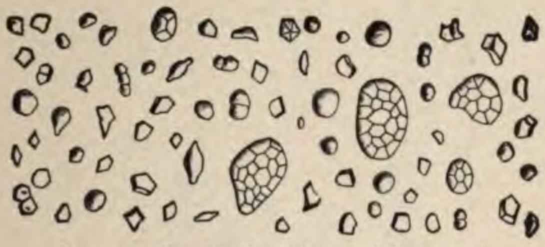


Fig. 35. Oat Starch. ×300. (Tschirch.)

MARANTA STARCH, OR BERMUDA ARROWROOT.

Genuine maranta starch is obtained from the rhizomes of *Maranta arundinacea* L., grown chiefly in Bermuda, St. Kitts, and St. Vincent.[1] In commerce, however, there appear to be three sorts obtained from two or more species. The grains of genuine Maranta starch (Fig. 36) are all simple (never in aggregates), the typical forms being rhombic, rhomboidal, and club-shaped. In addition to these we often find grains that are pear-shaped, triangular, and irregularly ovoid. The grains have very distinct excentric rings, but in place of a hilum there is usually a cross-fissure often of two curves resembling a soaring bird, or, less often, two crossing fissures.

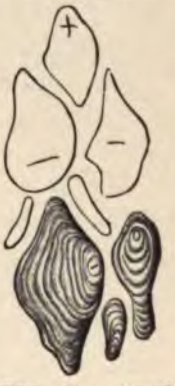


Fig. 36. Starch from *Maranta arundinacea*. (T) F. Hanausek.

The starch of *Maranta Indica* Tuss. has been described by Flückiger[2] and Wiesner.[3] Flückiger, in the second edition of his work on pharmacognosy, states that the differences between *M. Indica* and *M. arundinacea* are so slight that the latter ought no longer to be regarded a separate species. He also appears to consider the starch of the two "species" identical. The starch, purporting to have been derived from *M. Indica*, described and figured by WIESNER in the first edition of his work, consists mostly of grains in aggregate and, as noted by the author, is radically different from the Maranta type.

---

[1] For details of manufacture see T. F. Hanausek: Zur Charakteristik der Marantastärke. Pharm. Post. 1889, **22**, 177.

[2] Pharmakognosie des Pflanzenreiches. 1. Aufl. 1876, 710; 2. Aufl. 1881, 220.

[3] Die Rohstoffe des Pflanzenreiches. 1. Aufl. 1873, 271.

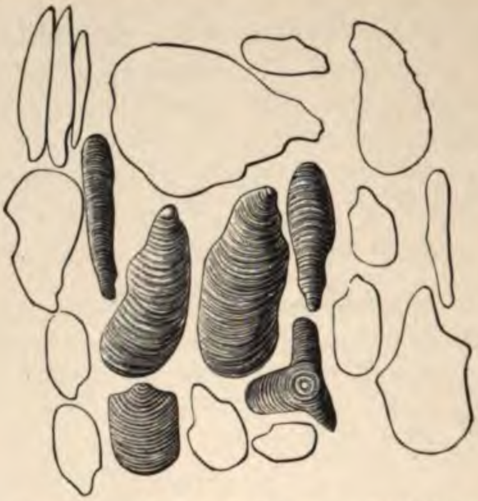


FIG. 37. Starch from *Maranta Indica* Tuss. (T. F. HANAUSEK.)
Type: club-shaped with strongly sinuous outline, shield-shaped, sinuous-rhomboidal. Maximum diameter 68μ.

As a matter of fact the starch grains of *Maranta Indica* (Fig. 37) are always simple. In form they are club-shaped, rhombic, or shield-shaped, with coves on the sides, or rarely hammer-shaped. The typical

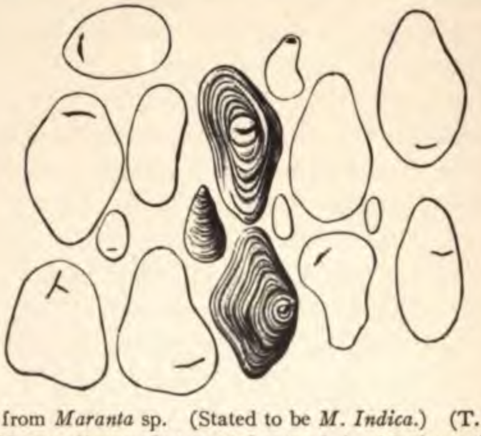


FIG. 38. Starch from *Maranta* sp. (Stated to be *M. Indica.*) (T. F. HANAUSEK.)
Type as in *M. arundinacea*, but strongly rounded. Maximum length 62μ.

forms resemble those of *M. arundinacea* with the irregularities exaggerated. Clefts are absent. The grains are 43–68μ long.

Another form (Fig. 38) probably the same as that described by v. Höhnel[1] as West Indian starch, has broadly ovoid, rounded rhombic, rounded club-shaped, or even muscle-shaped grains with a fissure at the hilum. They are 37–62μ long. The grains of this sort are characterized by their rounded form, those of *M. Indica* by their pronounced wavy, angular outline, while the grains of *M. arundinacea* are intermediate between the two.

CASSAVA STARCH. (Fig. 39.)

Cassava, manioca, mandioca, or tapioca starch is obtained from the tuberous roots of ***Manihot utillissima*** Pohl (*Euphorbiaceæ*), a plant grown in Brazil and most tropical regions. The individual roots often weigh 10 kilos and reach a length of one meter.

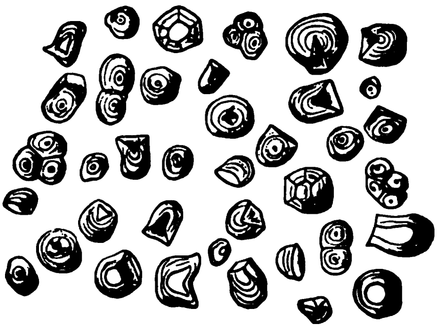


Fig. 39. Cassava Starch. (Tschirch.)

The starch is a fine white powder consisting in large part of aggregates (usually twins and triplets) of truncated grains. When resting on their flat surface the grains appear circular with a dark zone about the hilum, but when viewed from one side their kettle-drum or sugar-loaf shape is evident. A weakly refractive substance[2] extends from the center to the flat surface. The large grains are 14–26μ, the smallest 5–8μ. Tapioca is prepared from this starch by heating.

---

[1] Die Stärke und die Mahlproducte. Cassel, 1882, 31.

[2] Moeller regards this as an expansion of the hilum.

SWEET-POTATO STARCH.

Brazilian arrowroot or sweet-potato starch, obtained from the tuberous roots of *Batatas edulis* Chois, comes into commerce chiefly from Brazil and British Guiana.

The product is a gray-yellow, moderately fine powder consisting either of aggregates or the grains separated from aggregates. Usually the number of grains in these aggregates is more than in cassava starch (often 4–12).

The individual grains are hemispherical, sugar-loaf-shaped, club-shaped, and polygonal, the larger grains measuring 20–50μ. The hilum is excentric, mostly with radiating clefts; the rings are distinct.

CURCUMA STARCH, OR EAST INDIA ARROWROOT. (Fig. 40.)

This product, also known as Tik, Tiker, Tikor, Bombay, Malabar, and Tellicherry arrowroot, is obtained from the rhizomes of *Curcuma augustifolia* Roxb., *C. leucorrhiza* Roxb., and other species of *Curcuma*. The starch grains are always simple, flattened, elliptical, or ovate in outline, ending in a sharp or blunt point in which is the hilum. They have very distinct miniscus-shaped rings and vary up to 75μ and in rare cases up to 100μ in length.

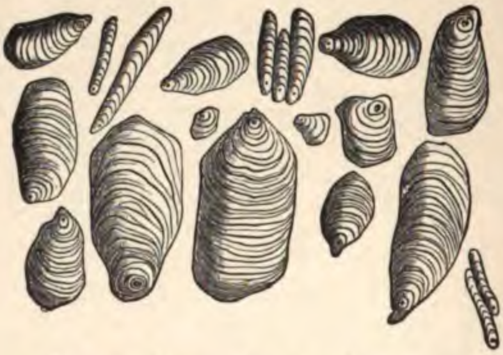


FIG. 40. Curcuma Starch. (TSCHIRCH.)

CANNA STARCH, OR QUEENSLAND ARROWROOT. (Fig. 41.)

The starch obtained from the rhizomes of various species of *Canna* (*C. edulis* Edw., *C. Indica* L., etc.) is characterized by the large grains which vary up to 130μ in length. The grains are simple, rarely in semiaggregates, flattened, broadly ovate, or reniform, or even fiddle-shaped, drawn out at the end into a short point. An excentric hilum is always evident.

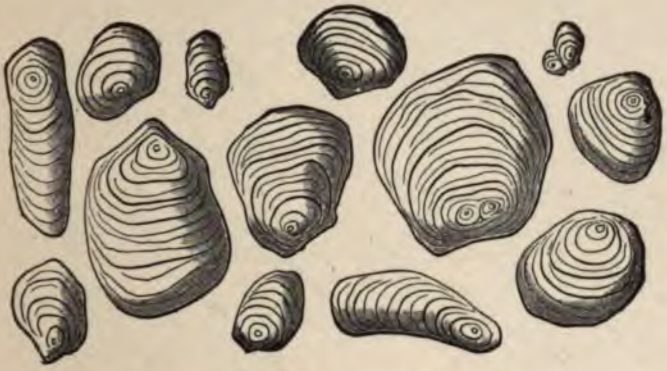


FIG. 41. Canna Starch. (TSCHIRCH.)

YAM STARCH, OR GUIANA ARROWROOT.

The tuberous roots of *Dioscorea sativa* L., *D. elata* L., and other species of *Dioscorea* yield fine white starch consisting of simple, flattened, irregularly ovate, elliptical, or club-shaped grains, with a more or less distinct point in which is located the hilum. The large grains are 14–80μ, usually 30–45μ, long.

BANANA STARCH.

Plantain or banana starch, also known as Guiana arrowroot, is made from the fruit of *Musa sapientum*, var. *paradisiaca*, and other species. Owing to the presence of fragments of the fruit flesh the ordinary product is reddish, but the purified product is pure white and has a weak violet odor. The simple starch grains are elongated, ovate, pear-shaped, and rod-shaped, with an excentric hilum and distinct rings. They are 30–76μ long.

SAGO STARCH. (Fig. 42.)

Genuine sago starch is obtained from the pith of several species of palm indigenous to India, the Sunda Islands, and the Philippines, of which *Sagus Rumphii* Willd. (=*Metroxylon Sagus* König), *S. lævis* Rumph, *S. farinifera* Lam., *Arenga saccharifera* Lab., *Borassus flabelliformis* L., are the most important. Species of *Cycas* and *Zamia* (order

Cycadaceæ) are also used for starch manufacture. The starch of *Sagu*[illegible] *Rumphii* consists of simple and compound grains; the latter are by fa[illegible] the most abundant and are characterized by the union of one large grain with two or more small cap-like grains (the intercalary grains of MOELLER). The large grain has a deltoid, triangular, or sugar-loaf form and usually measures 30–65μ. Sago is prepared from the starch by heating and contains all transitions from perfect grains to completely gelatinized and therefore unrecognizable grains. In swelling, the material of the inner layers first becomes gelatinized and runs out through a funnel-shaped canal formed during the heating.

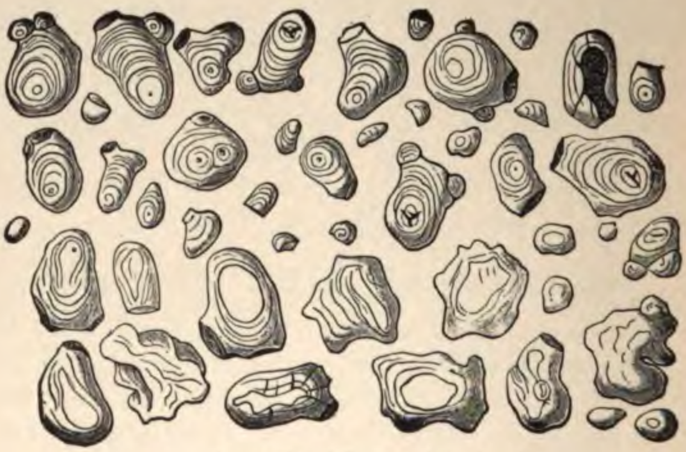


FIG. 42. Sago Starch, Partially Gelatinized. (TSCHIRCH.)

Formerly sago contained, in addition to starchy matter, a considerable amount of parenchyma cells, crystal rosettes, raphides, stone cells, and hairs, but at present the product is better purified.

LEGUMINOUS STARCHES.

The starches of legumes,[1] of which bean, pea, and lentil starch are the most important, are so similar in microscopic appearance that it is difficult to distinguish one from the other and well-nigh impossible to determine the constituents of a mixture.

---

[1] v. HÖHNEL: *loc. cit.*, 30. MOELLER: Mikroskopie der Nahrungs- und Genussmittel. Berlin, 2. Aufl. 1905, 262–273. TSCHIRCH u. OESTERLE: Anatomischer Atlas, 212, Table 20. VOGL: Die wichtigsten vegetab. Nahrungs- und Genussmittel, 1899, 160, 163. WINTON: Microscopy of Vegetable Foods. New York, 1915, 233.

BEAN STARCH. — The typical grains of the bean (Fig. 43) are bean- or kidney-shaped, broadly ellipsoidal, and oblong; in addition globular, ovoid, rounded ellipsoidal, and rounded triangular forms are not uncommon. Nearly all of the grains have distinct, sometimes very pronounced, rings and most of them have a cleft-shaped, ragged hilum, which, being filled with air, appears black. Radial clefts are rare. Length 24–57μ, usually 27–33μ.

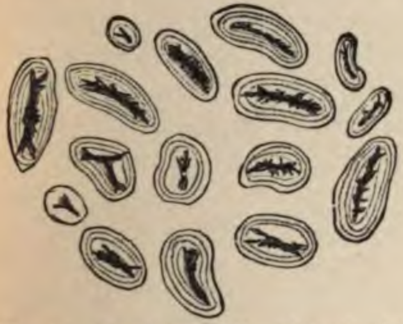


FIG. 43. Bean Starch (*Phaseolus vulgaris*). ×300. (T. F. HANAUSEK.)

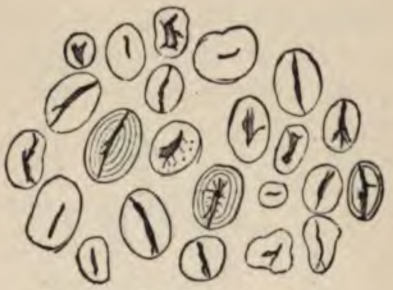


FIG. 44. Lentil Starch. ×300. (T. F. HANAUSEK.)

LENTIL STARCH (Fig. 44) consists of typical grains resembling coffee beans with a cleft running nearly the entire length, also of broadly ovoid, ellipsoidal to globular, kidney-shaped and dented forms. Length, 9–45μ, usually 20–40μ. Rings mostly indistinct, in many grains not evident at all.

PEA STARCH.—The starch of the garden pea (Fig. 45) is especially characterized by the swollen, humped, and irregular heart- and kidney-shaped grains. Forms such as occur in bean starch are also present. The hilum cleft is simple or branched, ragged, often quite irregular; an oblong hilum is sometimes evident. Rings are almost always distinct, as are often radial striations. Size 20–62μ, usually 35–47μ. The starch grains of vetches (species of *Vicia*) are similar but smaller.

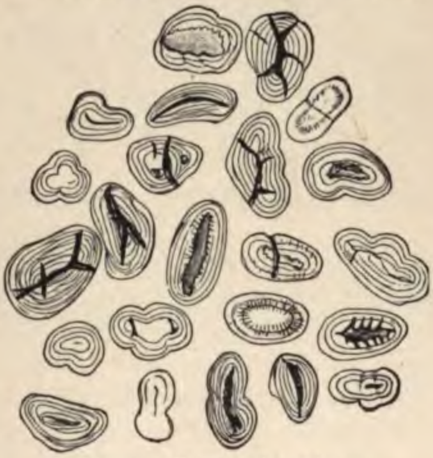


FIG. 45. Pea Starch. ×300. (T. F. HANAUSEK.)

INULIN.

Many plants produce, as reserve material in place of starch, a substance, found only dissolved in the cell sap, which was first discovered by Valentin Rose in 1804, in the root of elecampane (*Inula Helenium*), and was named, after this plant, inulin. This carbohydrate is chiefly formed in the subterranean parts of perennial composite plants, e.g., in the tuberous roots of the dahlia and artichoke (*Helianthus tuberosus*), in the roots of chicory (*Cichorium Intybus*) and dandelion (*Taraxacum officinale*), also in the roots and leaves of various campanulaceous plants.

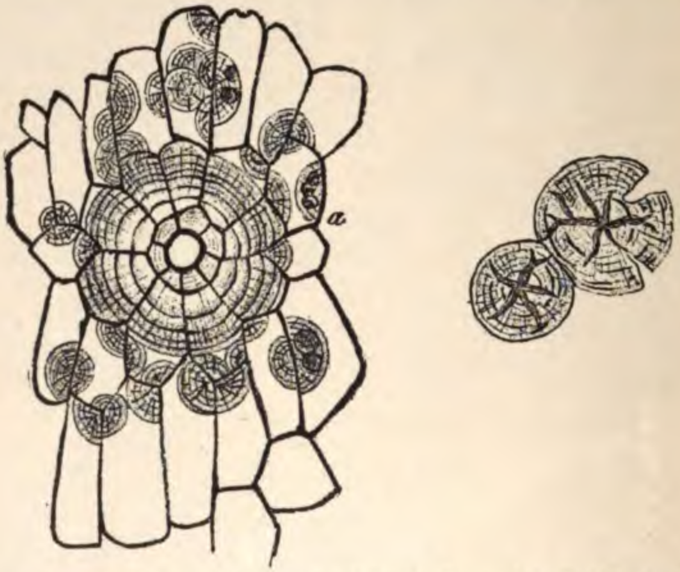


Fig. 46. Sphæro-crystals of Inulin from the Tuberous Roots of the Dahlia after Treatment with Hydrochloric Acid. (Reess.)
b more strongly magnified than *a*.

After drying these materials, the inulin separates in amorphus, glassy masses; if, however, the fresh material is placed in strong alcohol, the inulin, which is insoluble in this liquid, separates as beautiful aggregates of sphæro-crystals (Fig. 46), which give polarization crosses with crossed Nicols, dissolve slightly or not at all in cold water, but very quickly in warm water (50° C.), yield sugar on boiling with dilute mineral acids, and in some other respects closely resemble starch.[1]

---

[1] Note the resemblance of the sphæro-crystals shown in Fig. 46 to starch grains. For further particulars see Prantl: Das Inulin. München, 1870, and Tschirch: Angewandte Anatomie. Wien, 1889, 115. Fischer: Ber. Deutsch. Bot. Gesell. 1903, 107.

CHAPTER II.

VEGETABLE FIBERS.

THE fibers used in the arts are derived from the three natural kingdoms: the animal, the vegetable, and the mineral. Excepting metal wire and glass and silica wool, only a few are prepared artificially. The mineral kingdom yields but two fibers: asbestos, a fibrous variety of hornblende, and serpentine asbestos or chrysotile, which is obtained in large quantities in Canada. These are easily and certainly detected by their incombustibility.

The vegetable fibers are of two kinds, depending on their origin: either they are outgrowths of the epidermis of different parts of plants, in which case they are known as **Hairs**, or **Trichomes**, or else they are the so-called mechanical elements accompanying the fibrous strands (fibro-vascular bundles) of stems and leaves, in which case they are known as sclerenchyma fibers, or more commonly **Bast Fibers.** The fibro-vascular bundles of some plants are themselves the raw materials from which the commercial fiber is obtained. The property of a fiber, of chief importance in determining its adaptability for use in the arts, is its tensile strength; in addition it must be of sufficient length and, if used in textile fabrics, it must have pliability, fineness, and durability; furthermore, it must be easily obtainable and in sufficient quantities.

Animal fibers may also be classed in two groups: First, hairs covering the bodies of different mammals (e.g., wool, mohair, etc.), and, second, secretions of certain larval moths (silk), and of one group of mollusks (mussel silk).

Methods of examination are described under the individual fibers.

I. HAIRS (TRICHOMES).

Certain epidermal cells of the higher plants frequently grow most rapidly in a direction perpendicular to the surface, thus becoming extended beyond the surface of the organ in the form of hairs. Cotton is an example of a unicellular hair formed in this manner. If, during the growth of a hair, new cells are formed either by cross partitions or otherwise, the hair becomes multicellular. Hairs, being a part of the epidermis, like the latter are always covered with a membrane known as the **Cuticle.** This is composed of cutin, a substance related to the suberin of cork, and, like the latter, is impervious to water. Usually the membrane is structureless, rarely laminated, but often is wrinkled or striated on the outer surface. This cuticle is of technical importance in that certain properties of the fibers, notably the luster, are due to this formation. Later we shall see that the process of mercerization of cotton consists in part of the removal of the cuticle, thus increasing the luster of the fiber.

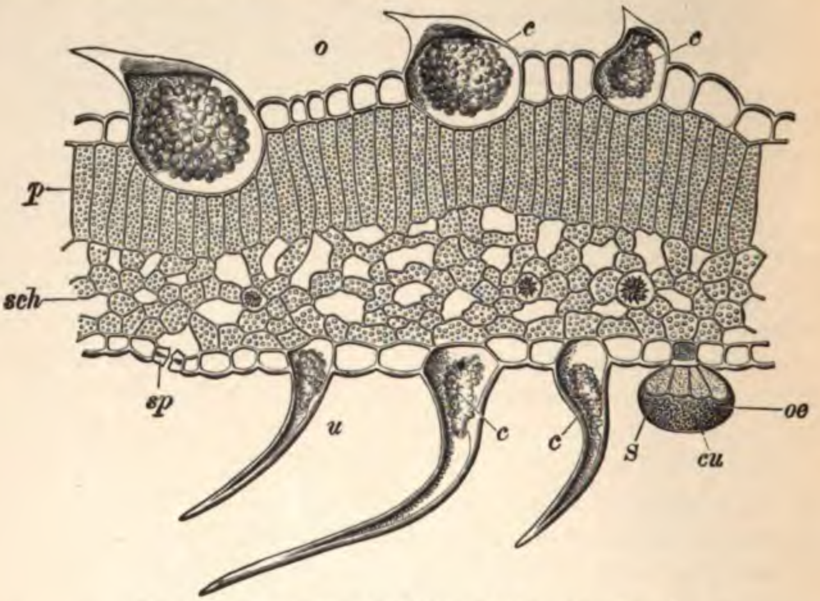


FIG. 47. Cross-section of the Hemp Leaf. (TSCHIRCH.)

o upper side; *u* lower side; *p* palisade tissue; *sch* spongy parenchyma; *c* cystoliths; *sp* stoma; *oe* oil-gland hairs; *S* secretion cells; *cu* cuticle.

An **Emergence** is an outgrowth formed, not only by the epidermis, but also by the underlying tissues. The thorns of the rose and the prickles of a gooseberry are common examples. The form, structure, and physiological function of hairs vary greatly, but in certain organs and in certain families are often characteristic and of special significance.

In the cross-section of the hemp leaf (Fig. 47) we find epidermal cells, on both sides, metamorphosed into unicellular hairs which are especially noteworthy because a coarsely warty body, consisting of calcium carbonate in a ground substance of cellulose, is deposited in each cell. These bodies, known as **Cystoliths**, are also found in the leaves of the rubber plant and other species of *Ficus*. We further note on the hemp leaf glandular hairs (Fig. 47, *oe*). These are very various in structure and secrete essential oil, resin, mucilage, or digestive juices. Most of them are multicellular and consist of a foot cell and one or more secretion cells. The secretion raises the cuticle of the cells and fills the cavity thus formed (Fig. 47, ***oe***, ***cu***).

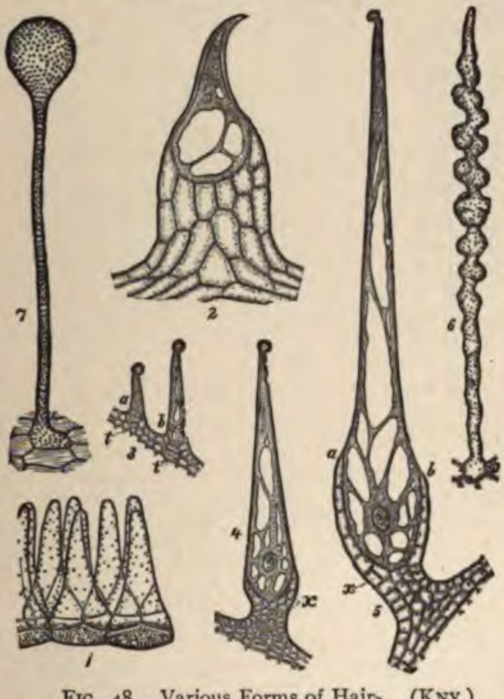


Fig. 48. Various Forms of Hairs. (Kny.)

1 from the corolla throat of *Primula Sinensis*; *2* from the stem of madder; *3–5* stinging hairs of the nettle; *6* hair from the flower of *Viola altaica*; *7* hair from the flower of the snapdragon (*Antirrhinum*).

In Fig. 48 are shown, in addition to papillæ, warty hairs and capitate hairs of various plants, and hairs of the nettle in different stages of development. The mature hair of the latter is hooked at the end and contains living protoplasm in streams.

Many families of plants are characterized by their peculiarly formed trichomes, examples of which are shown in Figs. 49–51.

Although great numbers of plants have hairs, only one—the cotton plant—yields a fiber of any considerable economic importance. Before we study the microscopic structure of cotton fiber, let us turn our attention to the properties of the constituents of cell walls, especially cellulose.

Cellulose.[1]

Cellulose is the chief constituent of the vegetable cell wall and forms, as it were, the framework of plants; it also occurs as reserve cellulose in the thickened layers of cell walls, especially in the seeds of many palms (areca nut, vegetable ivory, date stone, etc.), the coffee bean, nux vomica, etc. The membranes of fungous cells consist of a special modification known as fungous cellulose. Cellulose, or a substance resembling it closely in chemical properties, has also been found in the animal kingdom in the mantel of the Tunicates and in the ecto-skeleton of the Arthropods.

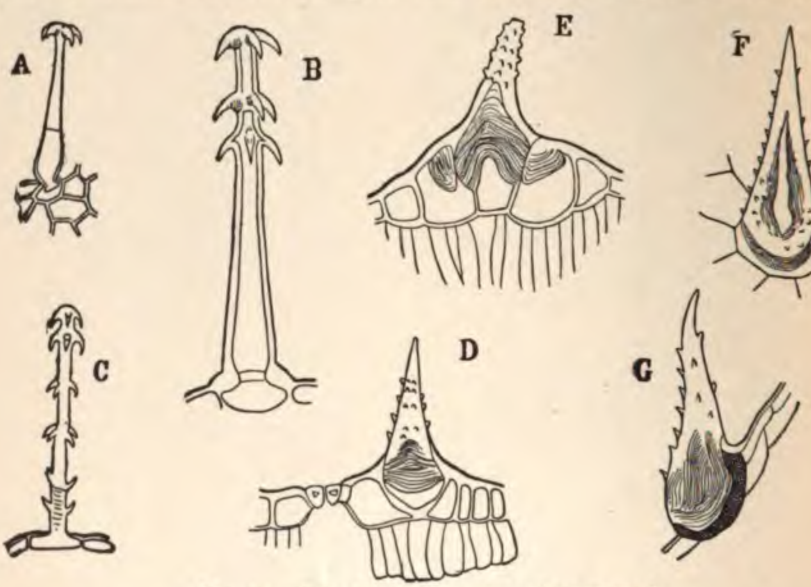


FIG. 49. Hairs of the *Loasaceæ*. (SOLEREDER.)

A–C unicellular anchor hairs: *A* and *B* *Eucnide lobata* Gray; *C* *Cajophora lateritia* Klotzsch.—*D* and *E* *Petalonix Thurberi* Gray: *D* cystolith hair; *E* trichome with calcified and strongly thickened walls, without cystoliths, but with cystoliths in adjoining cells.—*F* and *G* *Loasa chelidonifolia* Bth.: *F* dorsal view of cystolith hair against leaf; *G* side view.

The formula for cellulose given by PAYEN is $C_6H_{10}O_5$; by MITSCHERLICH and GERHARD, $C_{12}H_{20}O_{10}$, and by E. SCHULZE $(C_6H_{10}O_5)_x$; it is, however, highly probable, as suggested by WIESNER, SCHULZE, TSCHIRCH, and Gilson that the cell membranes are much more complicated in structure than was formerly believed. Newly formed cell membranes contain organic admixtures, or are composed of alteration products of cellulose; older membranes contain inorganic as well as organic substances, and in addition to typical cellulose, which may be converted by hydrolysis into dextrose, there is present **Hemicellulose,** the derivatives of which are different from those of cellulose. E. Schulze has shown that the cell wall contains, in addition to anhydrides of dextrose, **Pentosans,** which yield by hydrolysis various **Pentoses** (arabinose, xylose, galactose).

---

[1] See article, with numerous references, by T. F. HANAUSEK in Lueger's Lexikon der gesammten Technik, **3**, 14–19.

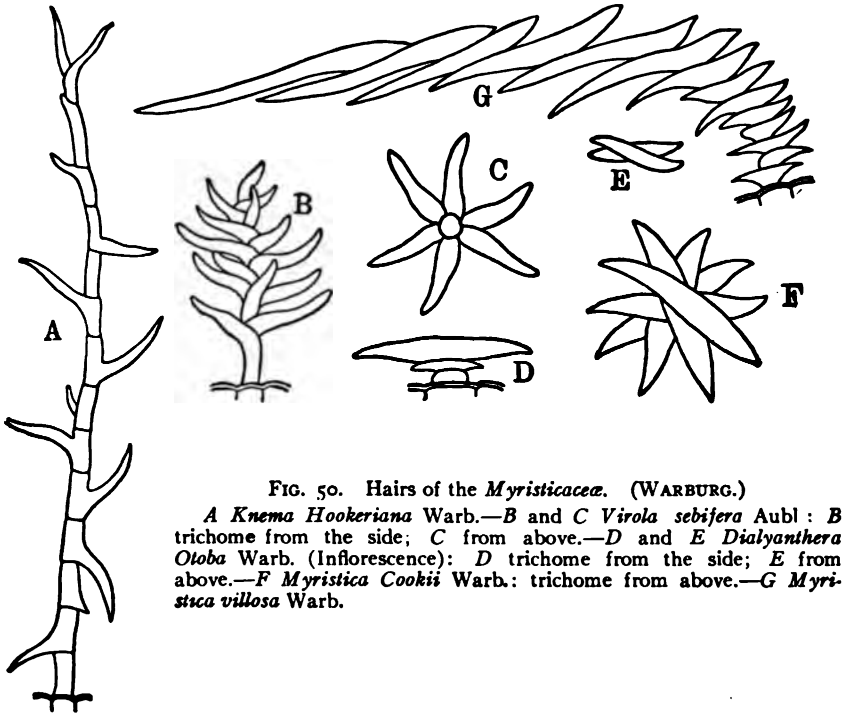


Fig. 50. Hairs of the *Myristicaceæ.* (Warburg.)
A Knema Hookeriana Warb.—*B* and *C Virola sebifera* Aubl : *B* trichome from the side; *C* from above.—*D* and *E Dialyanthera Otoba* Warb. (Inflorescence): *D* trichome from the side; *E* from above.—*F Myristica Cookii* Warb.: trichome from above.—*G Myristica villosa* Warb.

Typical cellulose is insoluble in water, alcohol, ether, diastase,[1] cold dilute caustic potash, and dilute acids. It dissolves in cuprammonia to a pale-blue gelatinous mass, from which it is thrown down by acids as a colorless precipitate which after drying becomes horny. Gilson has recently obtained sphæro-crystals of cellulose. It is dissolved by concentrated sulphuric acid and by a solution of zinc chloride in hydrochloric acid, but the chemical constitution is altered in both cases. Dextrine, dextrose, and humous substances are decomposition products. Iodine solutions color cellulose membrane yellow, which, on addition of sulphuric or phosphoric acid, changes to deep blue. A solution of iodine in potassium iodide, in which on long standing hydriodic acid has been formed, also produces this blue color. Chlorzinc iodine colors cellulose violet. The deportment of cellulose toward dyes is of great economic importance. Although it does not take up dyes directly to any appreciable extent, it has the property of precipitating, by mechanical surface attraction, mordants such as salts of aluminum, iron, chromium, and zinc, with weak acids, which, on treatment in the dyeing vat, form between the molecules of the fiber insoluble compounds with the colors.[1] Cellulose may be sensitized for dyeing by

---

[1] Reserve cellulose, according to J. Grüss (1896), is soluble in diastase.

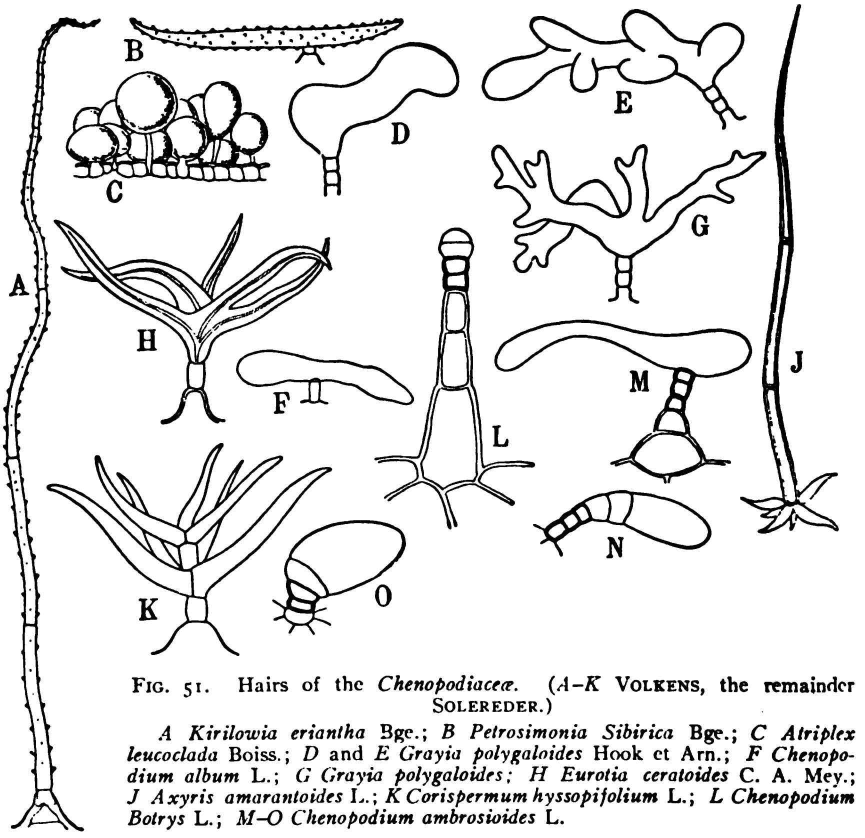


FIG. 51. Hairs of the *Chenopodiaceæ*. (*A–K* VOLKENS, the remainder SOLEREDER.)

A Kirilowia eriantha Bge.; *B Petrosimonia Sibirica* Bge.; *C Atriplex leucoclada* Boiss.; *D* and *E Grayia polygaloides* Hook et Arn.; *F Chenopodium album* L.; *G Grayia polygaloides; H Eurotia ceratoides* C. A. Mey.; *J Axyris amarantoides* L.; *K Corispermum hyssopifolium* L.; *L Chenopodium Botrys* L.; *M–O Chenopodium ambrosioides* L.

---

[1] See MICHAELIS: Beiträge zur Theorie des Färbeprozesses, die Färbungseigenschaften der Cellulose. Pflüger's Arch. ges. Physiol., 97, 634–640.

immersing in a solution of a caustic alkali such as sodium hydrate and quickly washing with water and dilute sulphuric acid[1]; if, however, the alkali acts for a longer period, the cellulose swells to a transparent mass which, after treatment for some hours with carbon bisulphide, is converted into a slimy, glutinous, water-soluble thiocarbonate, called by CROSS and BEVAN "**Viscoid.**" Cellulose may be again separated as an insoluble form by coagulating with common salt and heating at 100° C., in which form it is especially suited for sizing cotton and linen goods and paper, in place of the mineral sizes. It may also be converted into a tough, horny mass, which can be easily worked and colored, and from which can be made unbreakable vessels, etc.

Very weak caustic soda forms from the cell membrane **Metarabic Acid**; concentrated sulphuric acid dissolves cellulose, converting it into **Hydrocellulose** or **Amyloid**, which is colored blue by iodine and is the chief constituent of vegetable parchment. By oxidation of cellulose with boiling nitric acid, **Oxycellulose** ($C_{18}H_{26}O_{16}$) is formed; while by treatment with fuming nitric acid or a mixture of concentrated nitric and sulphuric acids the cellulose is converted into **Guncotton** (pyroxylin or nitrocellulose),[2] consisting of a mixture of di- and trinitrates. Treatment of the nitrates with camphor yields **Celluloid**, a material used for a great variety of purposes. **Collodion** is a solution of guncotton in ether. If cellulose is fused with potassium hydrate, potassium oxalate is obtained. Oxalates are also obtained by the long-continued action of chlorine, chlorinated lime, or Schulze's macerating mixture ($HNO_3 + KClO_3$), the process employed in the manufacture of oxalic acid being based on this principle.

That the cell membrane is not composed of a single substance is shown by microscopical examination after treatment with cuprammonia, or iodine and sulphuric acid. Many fibers, consisting essentially of cellulose, as, for example, ramie, apocynum fibers, and even cotton, show different colored layers with different solubilities.[3] These phenomena are of little interest from the industrial standpoint, but, on the other hand, changes in composition due to deposition of other substances are often of great practical importance. The material deposited may be an inorganic substance (e.g., tian; 3, Brazilian and Peruvian; 4, American (excepting Sea Island); and 5, Indian (Surate).

---

[1] This process, for some time used in preparing the fibers for dyeing, now is known as "mercerizing," and serves chiefly to give cotton the appearance of silk.

[2] WOLFFENSTEIN (Chem. Ztg. 1899, 847) states that nitrohydrocellulose is the proper term.

[3] MIKOSCH: Ber. Deutsch. Bot. Gesell. 1891, **11**, 306–312. T. F. HANAUSEK: *Ibid.* 1892, **12**, 1.

Sea Island Cotton is the most perfect and uniform sort; it has the smallest cross-section, a silky luster, and reaches 54.5 mm. in length. The fibers almost always are closely and regularly twisted, and there appears to be good evidence for the statement that the value of cotton increases with the increase in the number of twists of the fibers.[1]

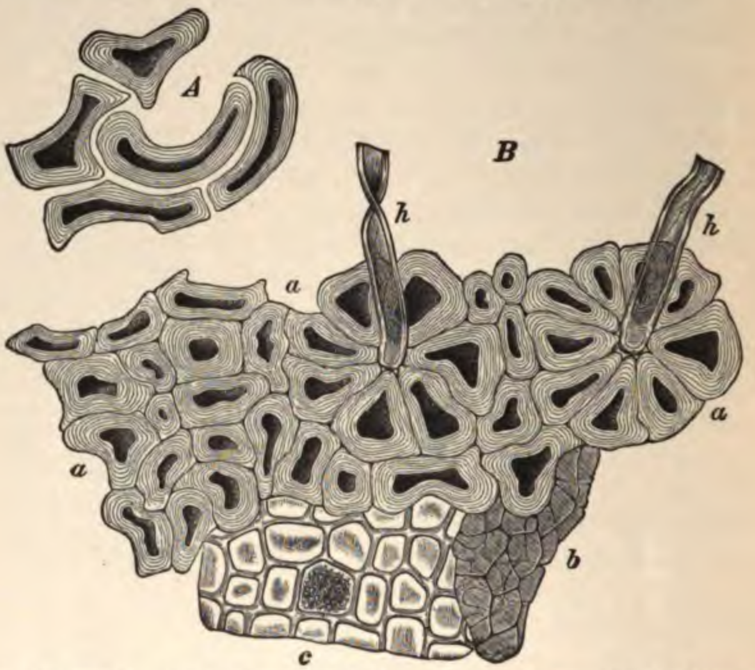


Fig. 53. Cottonseed. Outer Elements of Hull in Surface View. (T. F. Hanausek.) *A* isolated epidermal cells.—*B* three outer layers: *a* epidermis with *h* hairs; *b* outer brown layer; *c* colorless cells.

Egyptian Cotton, commonly known as Maco wool, resembles the

---

beitung und Handel sowie nach ihrer Stellung im Volksleben und in der Staatswirthschaft. Leipzig, 1902. Semmler: Die tropische Agricultur. Wismar, 1886, **3**, 481.

The following experiment station workers have studied the varieties grown in the United States: J. S. Newman, H. Benton, A. J. Bondurant, J. F. Duggar, W. H. Newman (Alabama); R. L. Bennett (Arkansas); R. J. Redding (Georgia); W. C. Stubbs, J. G. Lee, D. N. Barrows (Louisiana); E. R. Lloyd (Mississippi); F. E. Emery (North Carolina); J. M. McBryde (South Carolina); and others.

[1] The correctness of this statement, which the author has defended for years, has recently n disputed by W. Herbig, of Chemnitz, in a paper entitled: Beiträge zur Untersuchung Vorgänge, welche beim Mercerisiren der Baumwolle stattfinden. Ztschr. ges Text. Leipzig-Gohlis, III, 1899–1900, 17–19.

preceding, but consists not only of long but also of short fibers (31–38 mm.). The best variety is known as Gallini.

It is interesting to note that yarn of Egyptian cotton is finer than that of the same number made from American cotton. The fibers of the former are narrower, which, combined with their great flexibility, permits of their being closely twisted one with the other, thus making the yarn firmer and more durable. For this reason Maco wool is highly prized.

Brazilian and Peruvian Cotton are often mixed with other varieties. The staple measures 29–30 mm.

American Cotton, variously known as Texas, Mobile, Upland, New Orleans, etc., is produced in much larger amount than any other sort. Staple 25.9 mm.

Indian Cotton has a short staple (Hinghenhaut 29.2 mm., Bengal 28 mm., Oomrawuttee 25.4 mm., Broach 21.4 mm.) and the fibers are exceedingly variable in fineness, the coarsest occurring by the side of the finest. The quality is also seriously injured by imperfect methods of harvesting. For this reason Indian cotton is classed among the poorest on the market. The finest sort of cotton from the Orient is known as "Adenos".

MICROSCOPIC STRUCTURE.

Cotton fibers need no special preparation for microscopic examination; a few of them are simply spread out in a drop of water on the slide and covered with a cover glass. Each hair appears with the low power as a delicate colorless band which is twisted like a cork screw, although seldom regularly or for its entire length. The greater the number of turns in a given length and the greater the regularity of the turns, so much the greater is the commercial value of the fiber. Since no other fiber, that is no bast fiber, is twisted in this manner, fibers which show this characteristic can be identified as cotton with absolute certainty.

With stronger magnification (Fig. 54) the walls and lumen are clearly distinguishable, the breadth of the lumen being usually much greater than the thickness of the wall (*a*, *b*), although in exceptional cases the reverse is true (*c*). Thick-walled hairs are particularly abundant in the finer sorts. Care should be taken, however, not to confound such hairs with thin-walled hairs viewed on edge in which position, owing to their flattened form, they appear to have narrow lumens. Like all epidermal cells cotton hairs are covered with an exceedingly thin, structureless cuticle which is insoluble in cuprammonia. The presence of this cuticle serves to distinguish cotton from all bast fibers. On the surface of the cuticle are fine granules and striations which are particularly conspicuous when the fibers are examined dry or after immersion in dilute ammonia water. The silkiness, luster, and to some extent the power of absorbing dyes are dependent on the greater or lesser development of these cuticular granules and striations. The cell wall proper, consisting usually of more than one third the diameter of the hair, consists of nearly pure cellulose; only the innermost layer, which represents the remnant of the protoplasmic contents, contains proteid matter.

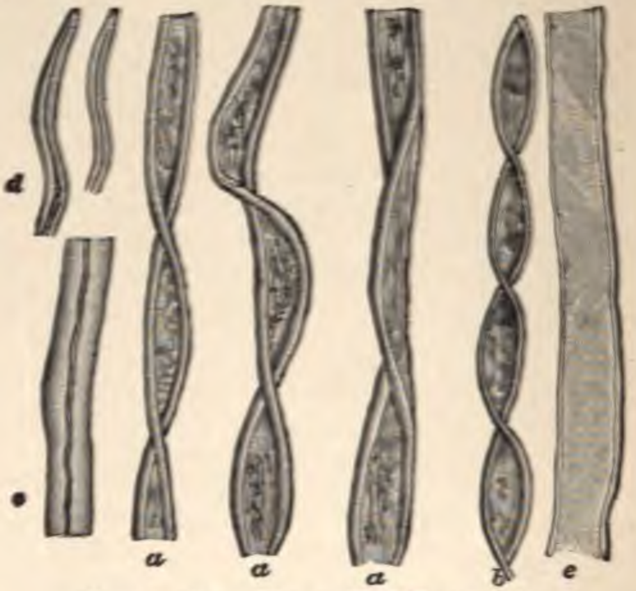


FIG. 54. Cotton Fibers. (T. F. HANAUSEK.)

a middle part of mature hairs; *b* more delicate hair with very regular twists; *c* very strongly thickened part of a hair; *d* ends of hairs; *e* dead hair.

The cotton hair has but one natural end, namely, the upper; in ginning, the hair is torn from the seed coat, leaving the lower end open. Commonly the apex is blunt, sometimes rounded or somewhat broadened. At this end the walls are very thick.

Iodine solution colors cotton fibers yellow, but subsequent addition of dilute sulphuric acid produces a deep-blue color and at the same time swells the fiber to a greater or less extent, according to the concentration of the acid, and finally dissolves it. Pure concentrated sulphuric acid can not be employed for this reaction since it carbonizes the fibers. Chlorzinc iodine produces a violet color, but aniline sulphate, or phloroglucin and hydrochloric acid, does not impart any coloration, thus showing that the fibers are not lignified. In concentrated nitric acid all the fibers, even those naturally yellow, appear colorless, while the cell walls swell greatly, especially toward the lumen, so that the latter is much reduced in diameter and, at the same time, the fibers are untwisted. Cuprammonia swells the walls with the formation of a blue color and eventually dissolves it, while the cuticle, which is insoluble in this solution, breaks up into wrinkled rings, short tubes, or spiral bands, which form constrictions in the swollen wall, giving it the appearance of being tied at intervals like the links of a string of sausage (Fig. 55).

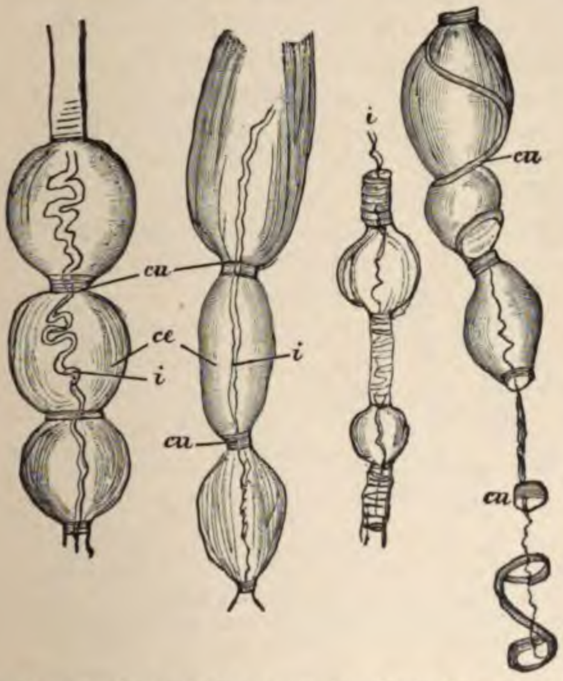


FIG. 55. Cotton in Cuprammonia. (T. F. HANAUSEK.)
ce cellulose greatly swollen (in the figure at the right completely dissolved) and constricted here and there by remains of the cuticle in the form of rings (*cu*); *i* inner tube.

The cuticle may also break up into irregular shreds. The inner layer of the wall not only does not swell but resists longest the solvent action of the reagent, forming, after the outer layers have disappeared, a narrow tube often with diagonal and spiral markings; at length, however, this is reduced to a coil of delicate threads and finally goes into solution, leaving only the fragments of the cuticle undissolved. It should be noted in this connection that these phenomena are considerably modified by the differences in the concentration of the solution, and that the different varieties of cotton deport themselves differently. A strong, freshly prepared solution almost immediately converts the fiber into a formless mass.

Fibers which do not fully conform to the types already described occur even in the best kinds of cotton. The fiber shown in Fig. 54, *e*, is an example of an extreme form. It consists of a flat, exceedingly thin-walled, untwisted band marked with delicate, often crossing, striations. Such hairs owe their peculiarities to the fact that they lost their vitality before the walls became thickened; they are known as **Dead Hairs.** They occur in all cotton, but are found in the greatest number in coarse varieties such as Indian, and in the least number in Sea Island.

A second kind of fiber consists of **Half-ripe Hairs**, in which the walls, although evident, are very thin and transparent; intermediate forms, between these and fully mature hairs with thick, sharply defined side walls, are also found.

These peculiarities are especially noticeable in thin cross-sections (Fig. 56), which are prepared by arranging a number of hairs in parallel rows in glycerine gum,[1] allowing the gum to dry until it becomes hard, and sectioning both gum and fibers with a razor. These sections are examined in water and again after treatment with iodine and sulphuric acid. In this manner ripe, unripe, and half-ripe cotton fibers may be distinguished from each other, and all of them from bast fibers. Cotton fibers s occur singly (never in groups like bast fibers); the contour in cross-

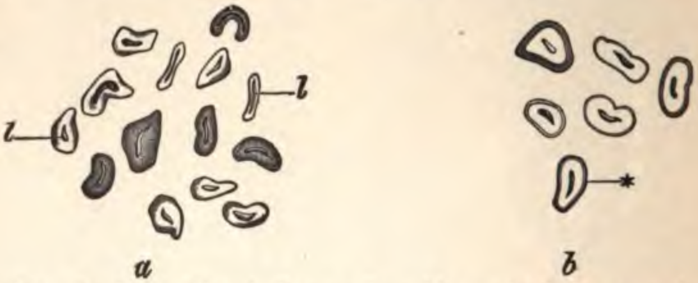


FIG. 56. Cotton Fibers in Cross-section. ×400. (T. F. HANAUSEK.)
a in water; *b* after treatment with iodine and sulphuric acid; *l* lumen. The double contour in *b* represents the dark-blue edge, the heavy line at * the cuticle colored yellow. The narrow sections in *a* are of half-ripe hairs.

---

[1] 10 grams gum arabic, 10 c.c. water, and 40–50 drops of glycerine.

section is elliptical, ovate, reniform, crescent-shaped (never circular, never polygonal like bast fibers); the contour of the lumen conforms to that of the fiber. Half-ripe fibers in cross-section are narrow, elongated, with linear lumen.

After treatment with iodine and sulphuric acid the sections of cotton swell to broadly elliptical or irregular forms without altering the shape of the lumen, the cell wall is colored blue (the outer layers often darker than the inner), while the cuticle, which is indistinctly evident as a delicate line, also the cell contents, are colored yellow.

If fibers from well-bleached cotton yarn or cotton fabrics are examined it will be seen that the cuticle is often wanting. This is due to the mechanical and chemical treatment to which the fibers have been subjected in the process of manufacture.

MERCERIZED COTTON.

It has already been noted that the cuticle, as well as the twisting, has an important influence on the luster of cotton fibers. It is obvious that any treatment which removes the cuticle and makes the surface of the fiber smoother, and which also untwists the fibers, must give the cotton a higher luster, and make it resemble more closely silk.

In 1850 J. MERCER discovered that by soaking cotton for a short time in caustic soda or caustic potash the appearance is strikingly altered. On this discovery is based the modern process of mercerization. Cotton, after dipping in caustic soda and washing in water and dilute acid, becomes more translucent, stronger, and more sensitive to dyes; it also takes on a peculiar luster. This process has been perfected in recent years and mercerized fabrics with a luster resembling that of silk are now made in large quantities. Attempts have also been made to impart a gloss to cotton by treatment with solutions of nitrocellulose and silk and in other ways.

The detection of mercerized cotton by microscopic examination is a very important, but not always easy, task. Immersion in alkalies or acids causes certain phenomena associated with the swelling of the fiber, and also almost completely removes the cuticle. But the method of application and the mechanical treatment are also of great importance. A permanent, silky luster and the closest resemblance to silk are secured only when the cotton is prevented from shrinking during the process of mercerization. This can be accomplished only by keeping the material stretched during the treatment with alkali. During treatment the fiber swells considerably and takes on, as noted by THOMAS and PREVOST,[1] the form of a many-times-bowed and crooked filament with an irregular, roughened, and wrinkled surface, and a more or less distinct, although contracted, lumen. The oval or round cross-section has a radial slit with often an enlargement in the middle from which radiate branches. If tension is employed in the mercerizing process, either during the treatment with alkali to prevent shrinking, or after this treatment to stretch out the shrunken fibers, two different conditions may arise: (1) the force with which the cotton shrinks during mercerization is so small that it can be counteracted by the stretching machinery employed in drying. In this case the stretched mercerized yarn has exactly the same dull, leathery luster and the individual fibers the same microscopic structure as has been noted for cotton mercerized without tension. (2) The shrinking force during mercerization is considerable and cannot be counteracted by the stretching machinery employed in drying. By employing a much greater force for stretching, the individual fibers not only become changed in microscopic structure but they take on a beautiful permanent silky luster. Examined under the microscope each fiber has the form of a straight, rigid, tightly stretched filament with a uniform, smooth surface and a lumen which is here and there invisible, the general appearance being that of a smooth, lustrous tube. In cross-section the fiber is round, with a more or less distinct, round, central opening with no evidence of a slit. The reasons for these differences are as follows: The result described in the first case is obtained when the cotton has a short staple, is loosely spun, loosely or not at all twisted, that is to say, when the fibers are easily displaced longitudinally, the stretching during mercerization causing the fibers to slide by one another so that an actual tension is not secured. The second case is that of a cotton with long staple closely spun and twisted, that is to say, one with fibers which are difficultly displaced longitudinally. The fibers are stretched and extended, and take on a perfectly smooth and therefore lustrous surface.[2]

The mercerized fibers shown in Fig. 57 illustrate the above statement. Each fiber is 20–35μ broad, straight, round, and smooth, with a lumen which is either visible the entire length, although narrow and varying in breadth (*a*), or is only visible here and there so that the fiber appears to have a row of streaks (*b*, *c*), or is quite invisible. Humps and depressions, corresponding to folds and twists of the original fiber, are sometimes present (*c*). The fibers, without evident lumen, resemble closely silk fibers, but treatment with cuprammonia brings out the lumen and, at the same time, certain marked differences between untreated and mercerized fibers. The latter swell uniformly in the reagent without marked constrictions and the lumen does not become folded or coiled, since the hair does not contract in length. The uniform swelling is explained by the absence of the cuticle;[1] only in rare cases where the fiber has obviously partly or entirely escaped the action of the mercerizing liquid is the cuticle present. Sometimes the inner tube is alternately enlarged and contracted, presenting in surface view the appearance of a series of rhomboids (Fig. 57, *e*). In cross-section the hairs are nearly circular, with groups of minute granules as contents. The characters of mercerized cotton of chief importance in diagnosis are (1) the smooth, cylindrical appearance; (2) the exceedingly irregular breadth of the lumen if visible the entire length, the rows of streaks if visible only in places; (3) the absence of a cuticle; (4) the uniform swelling in cuprammonia; (5) the nearly round cross-section.

---

[1] FISCHER: Jahresb. Leist. chem. Techn. 1898. Leipzig, 1899, **9**, 995 (with illustra-
See also EDUARD HANAUSEK: Dingler Polyt. Jour. 1898, 310, 10.

so A. FRÄNKEL u. P. FRIEDLÄNDER: Untersuchungen über Seidenbaumwolle
k Tech. Gewerbe-Museums in Wien. 1898, 8, 326.

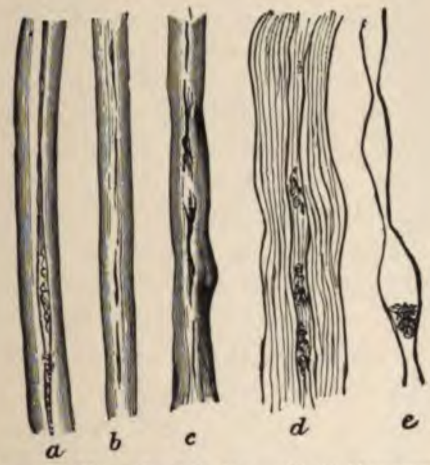


FIG. 57. Mercerized Cotton. (T. F. HANAUSEK.)

a, *b*, and *c* in water; *d* in cuprammonia; *e* contour of the lumen in cuprammonia with swellings and constrictions.

Since mercerization gives cotton an appearance closely resembling that of silk and at the same time increases its tensile strength and i sensitiveness to dyes, this process has, in the past few years, becon of great commercial importance. The action of caustic alkali appea to be partly chemical and partly physical. Sodium hydrate forr with cellulose an unstable compound known as **Alkali-cellulo** ($C_{12}H_{20}O_{10}\cdot NaOH$), which on washing with water is decomposed wi the formation of cellulose hydrate and the liberation again of caus alkali.

---

[1] See T. F. HANAUSEK: Technisch-mikroskopische Untersuchungen. Mittheil. k.k. Tech. Gewerbe-Museums, 1905 L. BŎSCALIONI: Sulle modificazioni provocate dai processi di mercerissacione nei filati di cotone Atti R. Inst. Bot. Univers. di Pavia. Nuova Seria. 7.

VEGETABLE DOWN.[1]

The fruit hairs of various species of the order *Bombaceæ* are variou: known as vegetable down, silk cotton, bombax wool, ceiba wool, edred végétal, kapok (in the Sunda Islands), paina limpa (in Brazil), pa de lièvre, ouate végétale, etc. Although the hairs have a beautiful sil luster, most of them have little strength and are almost worthless i textiles. It is stated, however, by GROTHE that the hairs of *Bomb heptaphyllum* L. make good yarn, especially if mixed with cotton.

Although the seeds are surrounded by a dense mat of hairs th latter do not spring from the seeds but from the inner layer (endocaı of the pod or from the dividing wall.

MICROSCOPIC STRUCTURE.

The hairs of all vegetable downs are unicellular, conical, lignifie with a strongly developed cuticle. Usually they are round in cro: section, not like cotton flattened and twisted. They are 1–3 cm. lor usually 20–37μ broad (maximum 54μ), and are either swollen or co tracted at the base. The hairs of most of the species vary from yellowi white to brownish, but those of *Ochroma lagopus* Sw., a species growi in the Antilles and South America, are dark brown.

In species of *Bombax* (*B. Ceiba* L., *B. Malabaricum* DC.) the wa of the hairs have a characteristic, finely reticulated thickening at the bas and are somewhat thickened at the end, but in other parts are very thi

The common silk-cotton or kapok tree (*Ceiba pentandra* Gärtn. *Eriodendron anfractuosum* DC.) grows in the East and West Indies ar various tropical regions. It yields, in addition to the fiber, an oil see

---

[1] **T. F. HANAUSEK**: Realenzyklopädie d. ges. Pharm. 1. Aufl., 8, 63–65. v. HÖHNE der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 36. WIESNE nzenreiches. Leipzig, 2. Aufl. 1903, 2, 264.

The deep-brown wool of *Ochroma lagopus* Sw. (Fig. 58) consists of moderately thick-walled hairs (walls 6–7μ thick in hairs 30–40μ broad) which break with the formation of splinters (*y*) or short elbows (*x*). They contain a granular material at the base and the apex (*b*, *e*), but are otherwise empty. The walls are especially thick at the base and the pointed apex. In addition to the typical hairs, appearing under the microscope of a deep-yellow color, are others which are nearly colorless, flattened, often much folded, with indistinct outline and finely striated surface. The typical hairs are 25–54μ, mostly 30–37μ, broad.

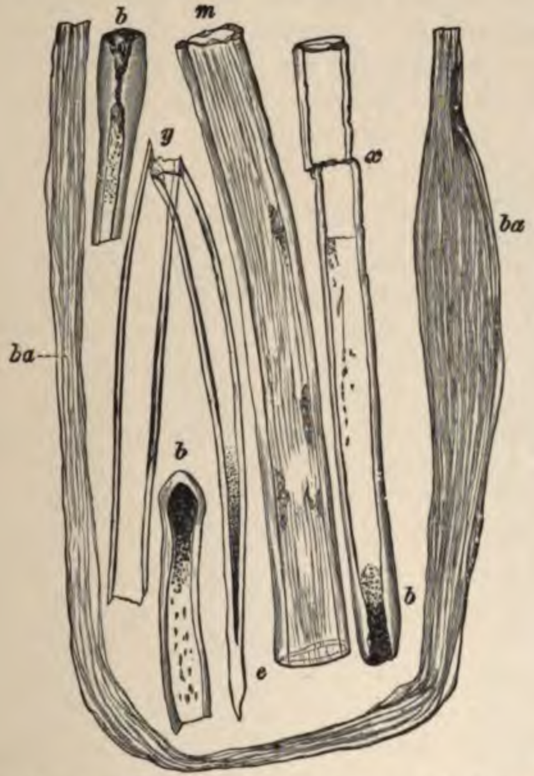


FIG. 58. Vegetable Down from *Ochroma lagopus*. (T. F. HANAUSEK.)
m middle piece; *b* basal piece; *e* apex; *x* and *y* broken places; *ba* a thin, flattened, and induplicate hair.

The different kinds of vegetable down are used chiefly for stuffing mattresses, cushions, etc.

II. FIBERS OF STEMS.

(Bast Fibers, Fibro-vascular Bundles, etc.)

While the technical fibers of cotton and other unicellular hairs are also the anatomical fibers—that is, each fiber is a vegetable cell—the so-called fibers of flax, hemp, jute, and the other raw materials now under consideration consist of several more or less closely united fiber-cells, or, in other words, of several anatomical elements. For the microscopical examination of fibers of this latter class, simple mounting in water is not sufficient, but each fiber must first be given a preliminary treatment to separate it into its cell elements. This separation may be effected by placing the object in a drop of water on a slide and teasing with a needle and forceps, but mechanical treatment of this sort is liable to scratch, crush, splinter, or otherwise injure the fibers. A better way is to treat with cold chromic acid solution, or, as recommended by VÉTILLARD, to boil for half an hour in a 10 per cent solution of sodium or potassium hydrate, wash with water, and rub with the finger.[1] The greater the care taken in the preparation, the less the fibers will be injured, and the more completely the fiber cells are isolated, the clearer the structure will appear under the microscope. Cross-sections are prepared by embedding a bundle of fibers in glycerine gum, allowing to dry, and cutting with a razor or microtome.

Since the physiological function of bast fibers is the same in all plants, it is not surprising that the general structure is also much the same. The recognition of the bast fibers of many plants and their distinction from those of other plants present great difficulties, and the beginner will do well to confine himself to a study of the commonest and best understood fibers. The leading fibers are here considered in detail, but only the chief characteristics of the less important ones are given.[2]

---

[1] See v. HÖHNEL: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 22, 23.

[2] Further details will be found in the following works. C. R. DODGE: A Descriptive Catalogue of Useful Fiber Plants of the World. 1897. v. HÖHNEL: Die Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905. MATTHEWS: Textile Fibres. New York, 3d Ed. 1913. VÉTILLARD: Études sur les fibres végétales textiles. Paris, 1876. WIESNER: Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903.

(a) Fibers of Dicotyledonous Plants.

FLAX.[1]

The flax of commerce consists of bast fibers obtained from several varieties of *Linum usitatissimum* L. The quality of the fiber and the yield depend to a large extent on the climatic conditions, methods of culture, and processes of separation from the stem. Early crops of flax yield a better quality of fiber than late. The dressing of the fiber comprises a series of chemical, physiological, and mechanical processes. By **Rippling**, the leaves and seed heads are removed. **Retting** consists in softening the tissues either by rotting in the open (dew retting), or in hot or cold water, or else by treatment with steam or chemicals, thus permitting the separation of the fibers. After **Breaking** between rollers or **Batting** by hand, the adhering woody matter is finally removed by **Scutching**. By **Heckling** the long fibers are separated from the **Tow** or short fibers mixed with adhering particles of wood and other impurities.

Linen yarn is spun from the bleached long fibers; tow yarn is an inferior product made from the tow. Whether a fabric consists of pure linen yarn or of tow yarn, or a mixture of the two, may be determined by microscopic examination as described on p. 77. Only one with long experience can detect tow yarn by its microscopic characters.

The fibers of commercial flax are 2–15 dm. long, highly flexible, soft, fine, very elastic, firm, and durable. Their color is gray (dew retted), steel gray (Courtray process), gray yellow, light yellow, or whitish. Flax can be easily and uniformly bleached, but can not be dyed so easily as cotton. The yarn does not ravel out like jute.

MICROSCOPIC STRUCTURE.

The fibers consist of groups of bast fiber cells, which are colorless, pointed, uniform in structure, and usually so strongly thickened that the lumen forms a very narrow double line. According to v. HÖHNEL the bast fibers are 4–66μ long (usually 25–30μ) and 12–30μ broad. Frequently cross-lines or cross-folds (incipient dislocations), often resembling pores, occur on the fibers, the latter frequently being swollen in such parts (Fig. 61, *A*). In worn-out linen thread or fabrics these characteristics are so marked that the wall appears distinctly striated, bruised, much broadened, with tumor-like swellings (*B*, *q*), all of which doubtless results from the treatment of the raw material. v. HÖHNEL,[1] who has studied these phenomena in many fibers, concluded that the simple cross-lines and folds result from inequalities of the radial pressure of the tissues in the plant, and are therefore of physiological origin. SCHWENDENER,[2] on the contrary, considers them as resulting from artificial influences during the process of preparation, since in fibers which are obtained by simple rotting in water such distortions are either completely lacking or are sparingly present and but feebly developed.

---

[1] T. F. HANAUSEK: Realenzyklopädie d. ges. Pharm. 2. Aufl. 1905, 5, 355. HANNAN: Textile Fibres of Commerce. London, 1902, 13. V. HÖHNEL: Die Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 42. MATTHEWS: Textile Fibres. New York, 3d Ed. 1913, 382. WIESNER: Die Rohstoffe des Pflanzenreiches. Leipzig, 1903, 2, 276.

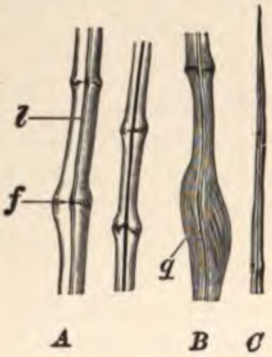


FIG. 61.

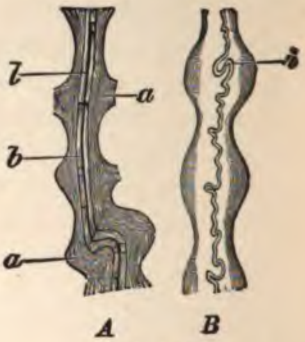


FIG. 62.

FIG. 61. Linen Fiber in Longitudinal View. (T. F. HANAUSEK.)
A fiber only slightly injured with *f* cross folds and *l* lumen.—*B* fiber strongly bruised with *q* diagonal striations of bruises.—*C* apex.

FIG. 62. Linen Fibers. (T. F. HANAUSEK.)
A after treatment with iodine and dilute sulphuric acid: *a* dark blue, partially dissolved outer layer; *b* inner stratified part; *l* lumen.—*B* in cuprammonia: *i* inner tube.

By cautiously treating flax fibers with iodine and rather weak sulphuric acid three layers may be distinguished: first, an outer dark-blue layer, becoming liquid in the reagent (Fig. 62, *A*, *a*); second, a longitudinally striated light-blue tube (*A*, *b*); and third, a narrow yellow tube with yellow contents. If, however, strong sulphuric acid is employed the whole cell wall changes to a blue swollen mass, and only the inner tube containing remains of the protoplasmic contents, persists for any considerable time. In cuprammonia (*B*) the cellulose wall goes into solution with the formation of a blue color and bladdery swellings, while the inner tube remains as a sinuous and in parts almost curled thread (*i*).

---

[1] Ueber den Einfluss des Rindendruckes auf die Beschaffenheit der Bastfasern der Dicotylen. Pringsheim's Jahrb. Wiss. Bot. 1884, **15**, 311, 316. Urticaceen, Apocynaceen, Asclepiadaceen.

[2] Ueber die "Verschiebungen" der Bastfasern im Sinne v. HÖHNEL'S. Ber. Deutsch. Bot. Gesell. 1894, **12**, 239.

Commonly flax fiber is considered as entirely non-lignified. According to v. HÖHNEL,[1] however, very short sections with lignified cross-walls intervene between long sections with walls of pure cellulose. ALOIS HERZOG determined the lignin in fibers from different parts of the plant by the methyl oxide method, and found that fibers from the root contained 3.8 per cent, from the middle of the stem 2.36 per cent, and from the tip of the stem 1.64 per cent, the results in each case being calculated to the dry material. By bleaching this small amount of lignin is entirely removed.

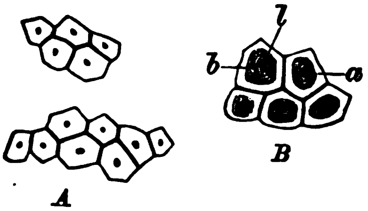


FIG. 63. Flax Fibers in Cross-section. (T. F. HANAUSEK.)

A in water.—*B* after treatment with iodine and sulphuric acid: *a* outer layer; *b* inner stratified layer; *l* lumen.

Cross-sections are indispensable for the careful study of bast fibers the appearance of these sections and the phenomena obtained on treatment with iodine and sulphuric acid being highly characteristic. Satisfactory cross-sections of yarn may be prepared if care is taken to straighten out the fibers and hold them tightly between pieces of elder pith, or, better, embed them in glycerine gum.

In cross-section the bast fibers of flax (Fig. 63, *A*) are sharply polygonal with 5–6 straight sides, and are rather loosely united in groups. As a rule, the lumen is very small, appearing as a mere point. Treated with iodine and sulphuric acid the section throughout is colored blue or violet, without a yellow outer layer (middle or outer lamella). In many cross-sections, however, an outer dark-blue portion (*B*, *a*) may be distinguished from the inner light-blue laminated portion (*B*, *b*).

---

[1] Zur Mikroskopie der Hanf- und Flachsfaser. Ztschr. Nahr. Unters. Hyg. Warenk. 892, 30.

It has already been noted that the fibers of flax usually have such thick walls that the lumen is reduced to a mere line. This, however, is not true of all bast fibers of the flax plant, as some of those found in the base of the stem have broad lumens and cross-sections quite different from those of the usual form. Fig. 64, *A*, shows the central part of a flax fiber of this kind with lumen about three times the thickness of the walls. Even near the ends (*C*) these fibers have a relatively broad lumen. The walls here and there are jointed (*B*) and with favorable illumination display a smooth outer layer, a delicately striated middle layer, and an inner membrane. In cross-section (*D*) the fibers are mostly sharply angular, although some are rounded. The lumen is conspicuous, as are also the three layers of the cell wall (*a*, *b*, *c*).

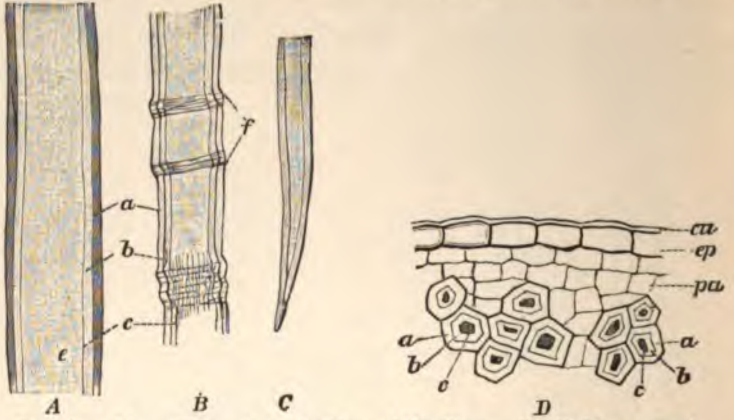


FIG. 64. Linen Fibers from the Base of the Stem. (T. F. HANAUSEK.)

A–C fibers with broad lumens in longitudinal view, ×400: *A* uninjured; *B* with *f* dislocations; *C* apex. *a* outer layer; *b* striated inner layer; *c* inner membrane; *e* lumen of fiber cell.—*D* cross-section of base of stem, ×200: *cu* cuticle; *ep* epidermis; *pa* parenchyma.

Still further removed from the type are those fibers found in the roots which, both in longitudinal view and cross-section, resemble strikingly hemp fiber. Cross-sections are elongated, flattened, rounded triangular, or almost elliptical. The lumen is large and contains only a small amount of protoplasmic contents. With phloroglucin and hydrochloric acid the walls give a rather light but distinct red coloration and are therefore lignified.[1]

---

[1] ALOIS HERZOG: Beiträge zur Kenntniss der Flachsfaser. Österr. Chem. Ztg. 1898, 310–312 and 335, 336. The article also contains good illustrations of longitudinal and ections of fibers from both the root and stem, those from the stem being from the ies.

The fibers of the basal part of the stem, as well as from the root, are largely found in the tow, therefore yarn made from tow is characterized by fibers with broad lumens, which easily might be mistaken for the very similar fibers of hemp. Tow fibers are also accompanied by epidermal cells, which at best are only partially removed in the mechanical preparation of the fibers.

The distinctions between linen and tow are then as follows:

1. Linen yarn consists of fiber cells, which mostly have narrow lumens and pointed ends, and is mostly free from other tissues of the stem.
2. Tow yarn consists of fiber cells with both narrow and broad lumens, and always contains epidermal cells.

Distinctions between flax fiber with broad lumens and hemp fibers are given under Hemp.

A. Herzog also calls attention to the fibers from the upper part of flax stems which he designates as "unripe". In cross-section these show very irregular forms, are rounded, often with reentrant angles, and have broad lumens containing abundant remains of protoplasmic contents. The ends are either pointed or rounded. These fibers occur in the tow.

HEMP.[1]

Since early times the bast fibers of the hemp plant (*Cannabis sativa* L.) have served chiefly for the manufacture of binding strings, cords, and ropes. Coarse yarn and fabrics are made in limited amount from the better grades. This fiber is also used to some extent in paper manufacture. The staminate plants yield the finest and best fibers, while the pistillate plants are commonly grown for the oily seeds and are not harvested until the fibers become brittle, strongly lignified, and of little value.

Hemp fibers are prepared from the plant by rippling, retting, breaking, and heckling as described for flax, although the processes are somewhat simplified. The broken hemp is known as **Bast Hemp**, the heckled as **Pure Hemp**, the latter being separated into shoemakers' and spinning hemp. The tow separated in heckling is used for upholstery.

---

[1] Hannan: Textile Fibres of Commerce. London, 1902, 21. v. Höhnel: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 47. Matthews: Textile Fibres. New York, 3d Ed. 1913, 416. Wiesner: Rohstoffe des Pflanzenreiches Leipzig, 2. Aufl. 1903, **2**, 300.

MICROSCOPIC STRUCTURE.

The technical fibers are of exceedingly variable length (in the giant hemp of Boufarik 3 meters long) and the fiber cells are 10–50 mm. long and 16–50μ broad. The cells are less uniform than those of flax. The lumen is very often rather broad, equalling or exceeding the thickness of the walls; sometimes, however, owing to the pronounced longitudinal striations of the wall (Fig. 65, *f*), its outline is indistinct. In disorganized fibers we find dislocations or folds resulting from compression, also swellings and cross-fissures, as well as the longitudinal striations already noted (*f′*). The ends of the fiber cells are mostly blunt (seldom somewhat pointed), or forked with 1–2 blunt side teeth (*e*). Forked ends, which have never been observed in flax, are strikingly characteristic of hemp, although they are not found on all the fibers. SCHACHT[1] finds the ends oftener forked than simple; WIESNER,[2] VÉTILLARD,[3] and CRAMER[4] maintain that the reverse is true. v. HÖHNEL[5] finds one forked fiber end out of 3–4 examined, the writer one out of 10. v. HÖHNEL[6] explains

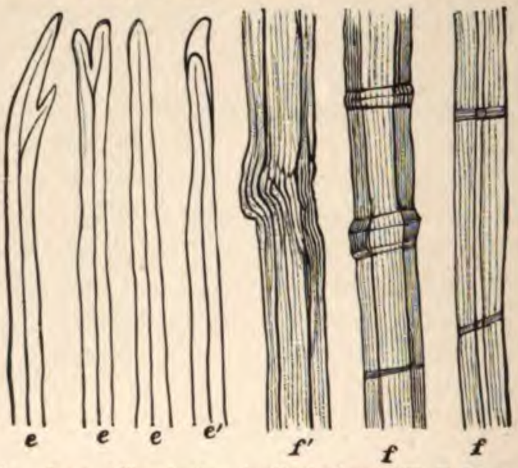


FIG. 65. Hemp Fiber in Longitudinal View. (T. F. HANAUSEK.)

f middle part with dislocations; *f′* middle part with conspicuous bruise; *e* and *e′* ends showing bifurcations.

---

[1] Die Prüfung der im Handel vorkommenden Gewebe. Berlin, 1853.

[2] Technische Mikroskopie. Wien, 1867, 110.

[3] Études sur les fibres végétales textiles. Paris, 1876, 77.

[4] Drei gerichtliche mikroskopische Expertisen betreffend Textilfasern. Programm des Züricher Polytechnikums, 1881, 22.

[5] *Loc. cit.*, 48–49.

[6] Ztschr. Nahr. Unters. Hyg. Warenk. 1891, 30.

these contradictory statements as follows: The tendency to form forked ends is greater the further south the variety is grown; northern hemp corresponds to the description of WIESNER, etc., Spanish hemp with that of SCHACHT, while Indian hemp has a still greater proportion of forked ends, often with long, spreading, compound branches or knotty protuberances with many short ends.[1]

Hemp fibers are slightly lignified, the color imparted by iodine and sulphuric acid being blue or greenish blue. After bleaching they show the reactions of pure cellulose. In cuprammonia the raw fibers swell greatly, the innermost layer of the wall forming often, although not always, a broad sinuous tube. Cross-sections are highly characteristic; the individual fibers are irregularly rounded or 3–6 sided with rounded corners, very distinctly laminated, and have a cleft-shaped, occasionally somewhat branched lumen, always without contents (Fig. 66). In iodine and sulphuric acid the cross-sections are colored blue excepting the outermost layer, the so-called outer or middle lamella, which forms a narrow yellow line about the blue inner layers (*q'*, *m*).

By the characters above described it is possible to distinguish hemp fibers from flax. This distinction is rendered especially easy if tissue elements of the hemp stem other than fibers are present, which is true of the incompletely heckled product commonly used for making binding-cords and wrapping-string. The most common, and therefore most important, of these accompanying elements are narrow, elongated, tube-like cells (?) completely filled with a deep-brown homogeneous material which is insoluble in the common solvents.[2] Even after boiling with potash these contents are little altered and pieces of various lengths with smooth fracture may still be found under the microscope. Another tissue not uncommonly present is the epidermis of the hemp stem which in coarse yarn often occurs in pieces of considerable size. The epidermal cells are polygonal, smaller than those of flax; the stomata are situated on small elevations and consist of two crescent-shaped guard cells without distinct accompanying cells. The epidermis also bears characteristic unicellular, very thick-walled hairs, geniculate near the base and bearing on the outer half numerous warts (Fig. 67). It remains to be noted that the parenchyma surrounding the bundles is rich in crystals of calcium oxalate, which are absent in linen.

---

[1] CRAMER's opinion of the value of the cell ends as a means of identifying hemp appears in the following quotation (*loc. cit.*, 22): "According to SCHACHT, the bast cells are often split at the ends with the formation of two points, while those of the flax are entire. WIESNER has already stated, in opposition to this view, that hemp fibers with forked ends are rare and I must support him. Supposing, however, that SCHACHT's statement stands undisputed, who would depend on it in a legal case? One should not forget that a bast cell 1 cm. long appears to be 1 m. long when magnified 100 times. What an excessive amount of time would be required in order to form a conclusion from a character of this nature!"

[2] CRAMER: *loc. cit.*

In linen fabrics containing carefully heckled hemp, however, the accompanying tissues described above are very seldom found. If it is further considered that in such fabrics the fibers show evidence of mutilation, that very often the ends are torn and crushed beyond recognition, and that finally, in well-bleached fabrics, cross-sections of the fiber no longer show the yellow lignified outer lamella, the latter having been in large part destroyed or removed, it is clear that it is very difficult to distinguish the two kinds of fibers and extreme caution must be exercised in reaching a conclusion. Only in cases where fibers are observed with unquestionably forked ends and with distinctly round cross-sections and cleft-like lumens, or where fragments of the brown pigment cells are found and identified beyond question, is it safe to assert positively

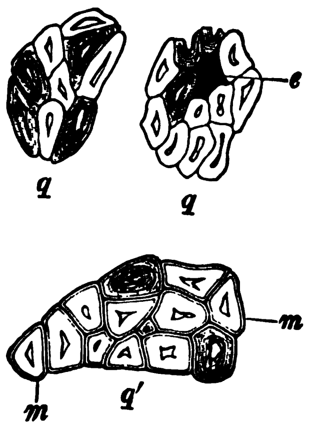


FIG. 66.

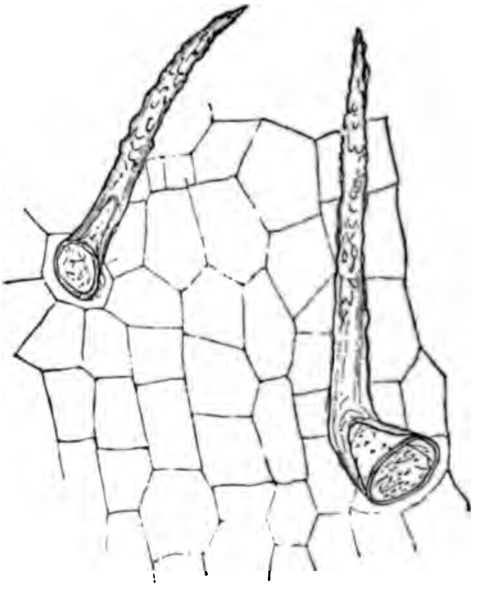


FIG. 67.

FIG. 66. Hemp Fibers in Cross-section. (T. F. HANAUSEK.)
q in water showing e intercellular space.—q' in iodine and sulphuric acid: m middle lamella.

FIG. 67. Epidermis of Hemp Stem with Two Hairs. (T. F. HANAUSEK.)

that hemp is present. Fibers with broad lumens, especially if longitudinal striations are present, do not furnish positive evidence, at least in surface view, since, as has been noted, such fibers may occur in flax. It should further be remembered that fine linen, that is linen with very fine threads, never contains hemp, and it is needless to examine any but heavy linen with coarse threads. The microscopist must have a large amount of experience before he can reach trustworthy conclusions; he must become thoroughly familiar with the appearance of both fibers by a careful study of numerous samples in all stages of manufacture—in the raw state, in yarn, in thread, in used and unused fabrics—and must pay special attention to the accompanying tissues. With this experience he will in most cases be able to reach positive conclusions.

JUTE.[1]

It is stated that about six species of the genus *Corchorus* yield fibers known as jute. Of chief importance are *C. olitorius* L. (the leaves and sprouts of which are prized as vegetables) and *C. capsularis* L., both of which are natives of India, but are now cultivated throughout the tropics. The jute plant is cut while in bloom, at which time it is several meters high, and usually is retted with water, seldom dew retted. The finer grades are exported in the form of fiber to be used with other fibers in the manufacture of various fabrics; the poorer grades are made into gunny cloth or gunny sacks, or used as paper pulp.

MICROSCOPIC STRUCTURE.

The technical fiber is of a peculiar gray-yellow or light brown-yellow color, rather soft, lustrous, strongly lignified, up to 3 m. long. After long use the fibers of the yarn unravel, owing to the splitting of the individual fiber cells. These latter are several millimeters long, 17–23μ broad, and show no lamination either in cross-section or longitudinal view. The lumen is usually rather broad, but varies greatly in different parts of the same fiber (Fig. 68, *f*, *f'*), being in some parts exceedingly narrow or even entirely closed (*f'*, *l*). The ends of the fibers are round. In cross-section (*q*) the closely united fiber cells are polygonal, with straight sides and very sharp angles, while the lumens are either oval (where the walls are thin) or circular (where they are thick). Treated with iodine and sulphuric acid the cross-sections are yellow throughout. The exceedingly variable thickness of the fiber cells furnishes a valuable means of identifying this fiber; furthermore, their close grouping in bundles is of value in diagnosis. Bruises and dislocations are not present, their absence being probably connected in some way with the absence of laminations. From these characters it is clear that jute has microscopic characters quite distinct from flax and hemp; it is quite similar to the fibers of *Abelmoschus*, *Urena*, and *Hibiscus* (Gambo hemp).

---

[1] T. F. HANAUSEK: Materialienkunde des Pflanzenreiches. Wien, 1891, 52 *Idem:* Jute. Realenzyklopädie d. ges. Pharm. 2. Aufl., **7**, 183. HANNAN: Textile Fibres of Commerce. London, 1902, 27. V. HÖHNEL: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 55. MATTHEWS: Textile Fibres. New York, 3d Ed. 1913, 399. PFUHL: Die Jute und ihre Verwendung. Berlin, 1888–1891. SEMMLER: Die tropische Agricultur, **3**, 644. WIESNER: Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903, **2**, 330.

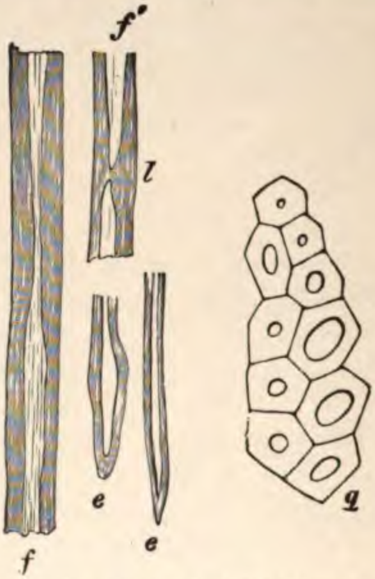


FIG. 68. Jute. (T. F. HANAUSEK.)

f middle part of fiber in longitudinal view with constricted lumen; *f'* with lumen interrupted at *l*; *e* ends of fibers; *q* cross-section.

A product resembling wool, known as **Cosmos Fiber**, *laine artificielle*, or artificial wool, is made from refuse jute, flax, and hemp. This should not be confused with shoddy or mungo.

GAMBO HEMP.[1]

This fiber, also known as Ambari fiber, closely resembles jute. It is obtained from *Hibiscus cannabinus* L., a plant growing in India. The fibers are yellow white to gray yellow, slightly lustrous, somewhat lignified. On treatment of a cross-section with iodine and sulphuric acid, it is evident that the lignification is not uniform throughout. In many fibers the walls are yellow, with a rather broad brown outer lamella; in others the inner layers of the walls are deep blue, only the outer lamella being yellow. Whole fibers treated in the same manner also show irregularities in color. These differences may explain some of the contradictory statements of different authors. Wiesner[2] states that the bast cells on treatment with iodine and sulphuric acid swell and become indigo blue, even to the innermost layers, while v. Höhnel[3] notes only a yellow coloration. v. Höhnel, however, employed dilute sulphuric acid, which does not give a blue coloration.

MICROSCOPIC STRUCTURE.

The technical fibers consist only of bast fibers. These are up to 6 mm. long, 14–16μ (according to v. Höhnel, mostly 21μ) broad, and are either blunt (Fig. 69, *e*), sometimes with a very short lobe near the end, or else pointed, the walls at the ends being in both cases very strongly thickened. The lumen in one and the same fiber shows very great variation in diameter; in some parts it is broad (f'), in other parts narrow (f''), and in still other parts disappears entirely (f''', l). Frequently it is alternately broad and narrow, as shown in Fig. 69, *f*. In cross-section the fibers are seen to be closely united, and are either polygonal with sharp angles and straight sides (q') or rounded polygonal to almost round or oval (q), the lumen in the first case being usually small, often a mere point, in the latter case large and oval. Cross-sections examined in water show a broad, distinct outer lamella, but concentric rings are evident only in some of the angular forms and in those but indistinctly.

---

[1] T. F. Hanausek: Gambohanf. Realenzyklopädie d. ges. Pharm. 2. Aufl. 1905, 5, 511. v. Höhnel: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 56. Matthews: Textile Fibres. New York, 3d Ed. 1913, 429.

[2] Die Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903, 2, 310.

[3] Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 44.

SUNN HEMP.[1]

Calcutta, Madras, Bombay, Conkanee, brown, or Indian hemp (kno in India as Ghore sun, Taag, chin-pat, chumese, and salsetti) is a text fiber obtained from *Crotalaria juncea* L. (*Papilionaceæ*).

The plants reach a height of 3 m. and are pulled when in blo (August). After partial drying they are water retted in bundles for fo

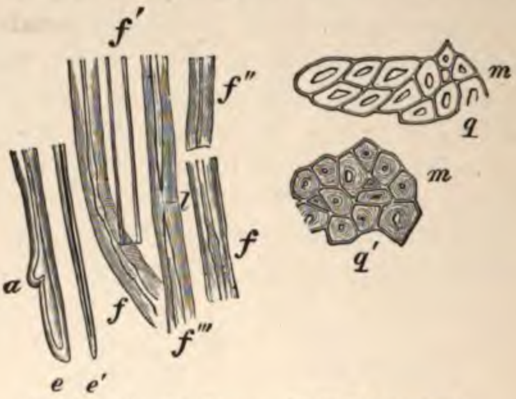


FIG. 69. Gambo Hemp. (T. F. HANAUSEK.)

f middle part of fibers in longitudinal view with irregular lumen; *f'* with very br lumen; *f''* with very narrow lumen; *f'''* with lumen interrupted at *l*.—*e* end of fiber w blunt apex and branch (*a*); *e'* pointed apex.—*q* cross-section with large lumens; *q'* cr section with very narrow lumens showing *m* middle lamella.

to eight days, and the fibers are obtained by stripping. They serve India for the manufacture of fabrics, but in England, France, a America are used only for paper, cordage, and bagging.

Sunn fiber has much the appearance of hemp. The fibers of t raw material are rather coarse, flattened, dark flax gray, and of varial length; after purification they are yellow-gray, somewhat lustrous, and moderately fine texture. The bast cells are 13–50μ, mostly 25–30μ, broa in longitudinal view partly smooth and partly striated, and also show cro bruises and dislocations (Fig. 70, *x*). The lumen is usually, but n always, thicker than the walls and sometimes contains minute granul (*m*, *p*). The ends are either rounded, very strongly thickened (*e*), or na rowed, with warty irregularities. Iodine colors the fibers golden yellow; iodine and strong sulphuric acid produce a peculiar swelling phenomenon (*m* and *q'*), whereby the outer yellow layer (*c*) becomes converted into a crumbling mass, over which flows the blue semi-liquid mass of cellulose (*v*), leaving behind a green-yellow inner tube (*i*). In cross-section as well as longitudinal view the fiber cells resemble closely those of hemp. The cross-sections are ovate, rounded triangular (*q*), with an elongated hilum. Treatment with iodine and sulphuric acid colors the thick outer layer (outer lamella) yellow (*q'*, *c*), the inner layers blue (*q'*, *v*). Sunn hemp and true hemp resemble each other so closely that it is questionable whether the two can be distinguished in paper.

---

[1] T. F. HANAUSEK: Realenzyklopädie d. ges. Pharm. 2. Aufl., **11**, 703. HANNAN: T tile Fibres of Commerce. London, 1902, 64. v. HÖHNEL: Mikroskopie der technis verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 54. MATTHEWS: Textile Fibres. New Yo 1913, 425. WIESNER: Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903, **2**, 311.

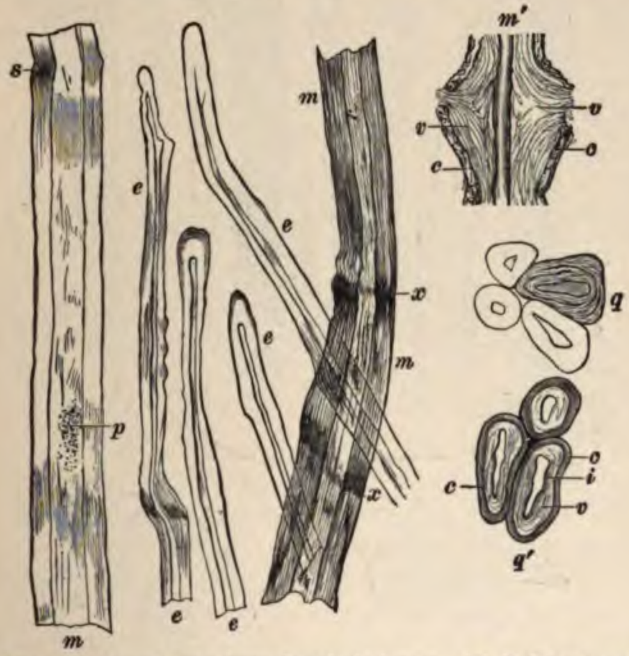


FIG. 70. Sunn Hemp from *Crotalaria juncea*. (T. F. HANAUSEK.)

m middle parts of fibers with *p* contents and *x* cross folds or bruises; *e* ends.—*m'* middle part of fiber and *q'* cross-section in iodine and sulphuric acid: *c* outer lamella; *v* cellulose membrane; *i* inner tube.—*q* cross-section in water.

In addition to the foregoing species two other papilionaceous plants yield fibers of use in paper manufacture. These are **SPANISH BROOM** (*Spartium junceum* L.) and **GERMAN BROOM** (*Sarothamnus vulgaris* Wim. = *Spartium scoparium* L.).

The long rush-like branches of the Spanish broom contain fine, soft, white, tough fibers,[1] made up of two kinds of bast fibers: first, narrow fibers (Fig. 71, *f'*), polygonal in cross-section (*q'*), and second, broad fibers with broad lumen (*f*), rounded elongated in cross-section (*q*). The narrow forms belong to the isolated subepidermal bast-fiber bundle of the branches, the broad forms to the bast of the fibro-vascular bundles. In all the fibers two layers of the wall are clearly distinguishable: an outer, very thin layer consisting of the lignified outer lamella (*m*), and an inner layer (*c*) consisting in large part of cellulose. These are seen in both longi-

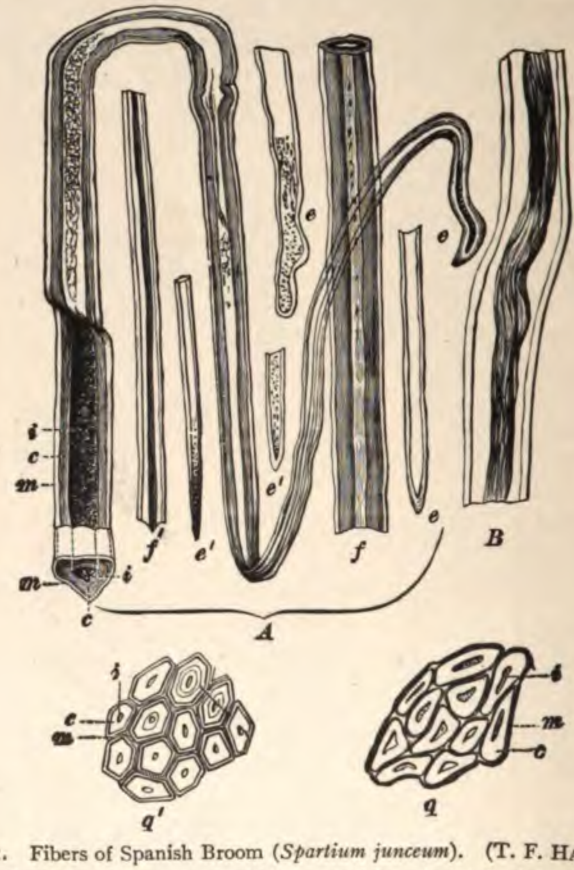


FIG. 71. Fibers of Spanish Broom (*Spartium junceum*). (T. F. HANAUSEK.)

A longitudinal view in water: *f* middle part of broad and *f'* of narrow fibers; *e* end of broad and *e'* of narrow fibers.—*B* longitudinal view after boiling in potash.—*q* cross-section of broad and *q'* of narrow fibers: *m* middle (outer) lamella; *c* cellulose wall; *i* lumen with contents.

---

[1] T. F. HANAUSEK: Realenzyklopädie d. ges. Pharm. 1. Aufl., 8, 91.

tudinal view and cross-section and are marked characteristics of this fiber. Many of the fibers display cracks and enlargements, but in other respects they are quite uniform in structure.

In fibers boiled in potash (*B*) a sinuous tube is evident. After treatment of cross-sections with iodine and sulphuric acid the yellow middle (outer) lamellæ form a bold network.

The narrow fiber cells are 10–12μ broad and their cross-sections are sharply polygonal, with lumen forming a mere point or a cleft. The broad fibers vary up to 20μ in breadth, usually 17μ, and their cross-sections resemble those of hemp, except that they are smaller and have a broad middle (outer) lamella.

German broom has practically the same structure.[1]

HOP FIBER.[2]

The bast bundles of the hop plant (*Humulus lupulus* L.) are used in Europe to a considerable extent for the manufacture of paper. They are isolated from the hop stems by the Nördlingen process, which consists in boiling in dilute soap-and-soda solution, washing, boiling in acetic acid, etc. The fibers are deep red brown, 20–80 cm. long. The bast fiber cells (Fig. 72, *f*) are smooth, usually striated, 23–30μ broad, and for the most part have thin walls, broad lumens, and broad rounded ends (*e*), although some are narrow, very thick-walled, and pointed (*f′*, *e′*). Cross-sections (*q*) resemble those of hemp, but are mostly narrower, laminated, and after treatment with iodine and sulphuric acid display blue walls and yellow granular contents. The fibers dissolve in cuprammonia much like those of flax. Their identification in paper pulp is exceedingly difficult, as the microscopic appearance, which at best is not very characteristic, is much altered in the process of manufacture. Of considerable value are the accompanying tissue elements, especially the so-called climbing hairs, which are unicellular, with equal or unequal hooked branches and strongly silicified walls.

---

[1] v. Höhnel: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 60.

[2] Jahresb. Wien. Hand. Akad. 1882, 15–19. T. F. Hanausek: Hopfenfaser. Realenzyklopadie d. ges. Pharm. 2. Aufl. 1905, 6, 420. Hannan: Textile Fibres of Commerce. London, 1902, 26. v. Höhnel: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 58.

NETTLE FIBERS.

Most plants of the nettle family (*Urticaceæ*) have long, flexible bast fibers well suited for use in textile fabrics. In previous centuries [1] a textile fiber was obtained from the common stinging nettle (*Urtica dioica* L.), and, more recently, since the isolation of fibers has been placed on a more practical basis the industry has been revived.[2]

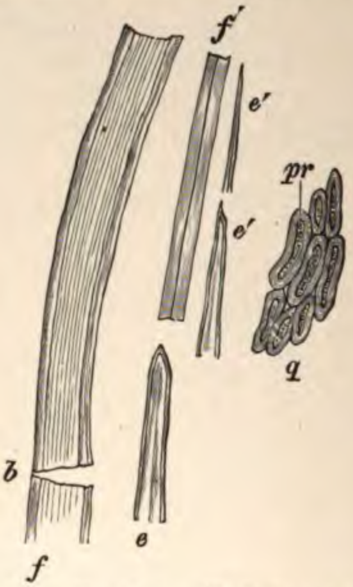


FIG. 72. Hop Fiber. (T. F. HANAUSEK.)

f middle part and *e* end of a broad fiber; *f'* middle part and *e'* ends of a narrow fiber, *b* broken place.—*q* cross-section with *pr* contents.

The fibers [3] are long, fine, flexible, soft, and sufficiently firm. The bast cells are of irregular diameter, as is shown by the great variation in size of cross-sections of the same fiber (Fig. 73, *a*). Enlargements of the fiber cell (and lumen) occur not only in the body of the fiber, but often also at the ends, so that the latter are spoon- or spatula-shaped (*e'*). Commonly the ends are blunt, rounded, and often, according to V. HÖHNEL, are forked. The cell wall is longitudinally or diagonally striated and is uniform in thickness, thus differing from the irregularly thickened wall of the cells of hemp fiber. Cross-markings (*f*, *p*), which might be taken for pore canals, are conspicuous on the surface which in the plant was adjacent to pith cells and quadrilateral crystal cells. Most of the fibers have finely granular contents colored yellow by iodine. Treatment with iodine and sulphuric acid colors the walls blue, thus showing that they are not appreciably lignified. WICKE,[1] however, states that they are silicified. In cuprammonia they dissolve quickly. Cross-sections (Fig. 73, *q*) show single fibers or loosely united groups of 3–6, seldom 9, fibers. The cells in cross-section are elongated or rounded ovate, sometimes reniform, never polygonal, with distinct laminations; the lumen is elongated, seldom narrow triangular, almost always with evident contents. In breadth they are 30–60μ (according to v. HÖHNEL up to 70μ, according to MOELLER up to 120μ).

---

[1] BOEHMER: Technische Geschichte der Pflanzen. 1794. **1**, 543.

[2] J. MOELLER: Die Nesselfaser. Polyt. Ztg. 1883, Nos. 34, 35.

[3] T. F. HANAUSEK: Realenzyklopädie d. ges. Pharm. 2. Aufl., **9**, 357. V. HÖHNEL: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 52.

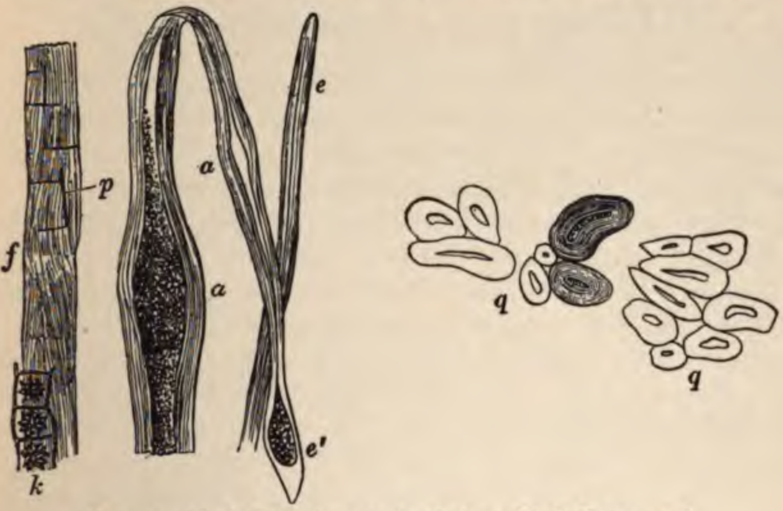


FIG. 73. Nettle Fiber from *Urtica dioica*. (T. F. HANAUSEK.)

f middle part of fiber with diagonal striations so strongly developed that the lumen is no longer visible; *p* impressions of parenchyma cells; *e* blunt and *e′* spoon-shaped ends of fibers, *a* inflated portion.—*q* cross-sections.

Fibers obtained with the aid of hydrochloric acid present a fine appearance owing to their white color and silky luster, but this advantage is gained at a loss of firmness.

---

[1] Bot. Ztg. 1861, 97, cited in SOLEREDER: System. Anatomie der Dicotyledonen, 875.

RAMIE.[1]

Of much greater importance than the fibers of the common nettle and the closely related Siberian species (*U. cannabina* L.), as well as the American representatives of this family such as *Laportea Canadensis* L., is ramie, also known as rhea fiber (Chinese, *tchoumâ*), the bast fibers of the ramie plant, or Indian snow nettle (*Boehmeria nivea* L.).

The plant is a native of southeastern Asia, but is cultivated in China, Japan, the Sunda Islands, East Indies, and North America.[2] At the present time the fibers are usually separated by machinery, although in China hand labor is still employed.

MICROSCOPIC STRUCTURE.

The crude fiber, or bast, consists of narrow yellow-gray or greenish-yellow strap-shaped fiber bundles. From this is prepared the textile fiber, or "cottonized" ramie, which is blinding white, very fine, with an almost silky luster, and consists of single bast cells or groups of cells. The length of the cells varies up to over 20 cm. (according to **Hassack** on the average 15–25 cm.), in exceptional cases up to 58 cm. They are 20–80μ broad, or, in other words, among the broadest of all the vegetable fibers used in the arts. The cell walls are moderately thick, their thickness being much less than the breadth of the lumen, and show in longitudinal view striking dislocations (Fig. 74, *f*), also longitudinal fissures (*r*) which often are crossed by darker transverse clefts. The broad lumen, the dislocations, the striations, and the fissures of the walls are the striking characteristics of ramie. Light-yellow, finely granular masses are contained in the fiber cells. Toward the ends (*B*) the fiber is narrow and the lumen is finally reduced to a line; the apex, however, is blunt. Since the fibers are flat the lumen appears broad only when they rest on their flat sides; when they rest on the narrow sides the walls appear very thick and the lumen is reduced to a narrow line.[1] The fibers swell greatly and become blue on treatment with cuprammonia, without forming barrel-shaped forms or dissolving completely. In iodine the walls become yellow, the contents golden brown, rarely so dark that the color might be regarded blue black or brown violet. On treatment with iodine and sulphuric acid the fiber displays a broad yellow-green inner tube, little acted on by the reagent,

---

[1] **Favier**: Les orties textiles. Paris, 1881. E. **Fremy**: Chimie végétale. La Ramie. Paris, 1886. **Grothe**: Chinagras und Nesselfasern. T. F. **Hanausek**: Ramie. Realenzyklopädie d. ges. Pharm. 2. Aufl., **10**, 554. **Hannan**: Textile Fibres of Commerce. London, 1902, 47. C. **Hassack**: Ramie, ein Rohstoff der Textilindustrie. Jahresb. Wien. Hand. Akad. 1890. This paper gives an exhaustive account of the distribution and culture of the plant as well as a detailed description of the fiber. *Idem:* Die Ramie. Ztschr. ges. Text. Indust. 1898–99, Nos. 13, 14, 16, 17, 20. v. **Höhnel**: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 52. **Matthews**: Textile Fibres. New York, 3d Ed. 1913, 410. **Moeller**: Polyt. Ztg. 1883, No. 34. A. **Schulte**: Hofe's Die Ramiefaser und die wirthschaftliche Bedeutung für die deutschen Kolonien. Berlin, 1898. H. **Semmler**: Trop. Agr., **3**, 665. **Wiesner**: Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903, **2**, 318.

[2] **Dodge**: The Cultivation of Ramie in the United States. U. S. Dept. Agr. Rpt. 1895, **7**, 63.

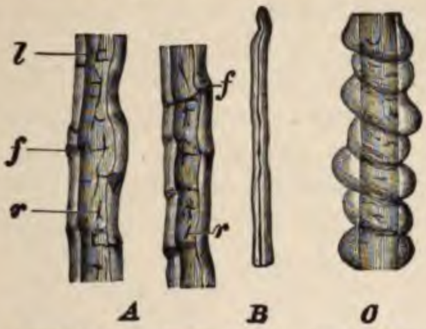


FIG. 74. Ramie in Longitudinal View. (T. F. HANAUSEK.)

A middle part in water: *f* bruise or dislocation; *r* longitudinal cracks; *l* lumen.—*B* end in water.—*C* middle part after treatment with iodine and sulphuric acid.

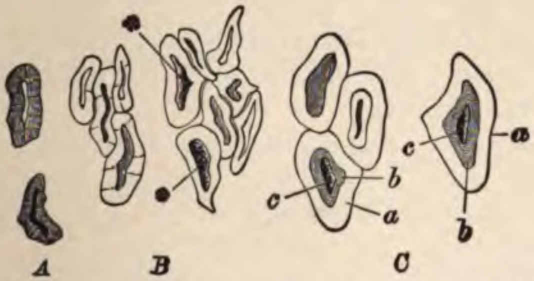


FIG. 75. Ramie in Cross-section. (T. F. HANAUSEK.)

A isolated fibers with radial cracks and *B* groups of fibers, in water; * yellow, finely granular contents.—*C* after treatment with iodine and sulphuric acid: *a* deep-blue structureless mantel; *b* light-blue laminated layer; *c* lumen with yellow-green inner tube and golden-yellow contents.

---

[1] HASSACK (*loc. cit.*, 12) gives the following measurements: the fiber cells are 20–82μ broad, commonly 40–60μ; the lumens are 21–45μ broad or $\frac{1}{2}$–$\frac{1}{3}$ of the entire breadth of the fiber; the walls are 9μ thick. The same author also considers the difference in appearance when viewed on the side and on edge as characteristic. Of more value, in the writer's opinion, is the enormous breadth.

broad collenchyma layer is a broad, continuous sclerenchyma girdle to which belong the large fibers (*q*). Since these are rather loosely united the groups found in cross-section contain but a few individuals. Within the closed girdle of fibers is a layer of delicate parenchyma which in turn incloses an interrupted girdle of cylindrical bast bundles, the fiber cells of which are the narrow forms resembling those of flax (*q'*).

The fibers are colored red brown by iodine solution and deep blue by iodine and sulphuric acid; they are distinctly non-lignified throughout.

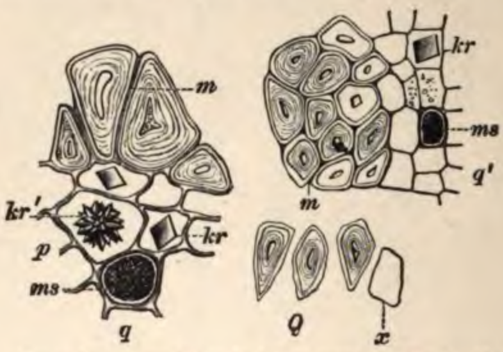


FIG. 77. Paper Mulberry Fiber in Cross-section. (T. F. HANAUSEK.)

q group of large fibers; *q'* group of small fibers, *Q* individual fibers. *m* outer lamella (*x* outer lamella separated from other layers); *ms* latex tubes; *p* parenchyma; *kr* single crystals; *kr'* crystal rosettes.

In paper made from this fiber constituents from the wood and pith are often present (see Examination of Paper, p. 121).

(b) Fibers of Monocotyledonous Plants.

MANILA HEMP.[1]

The fiber known as Manila hemp, Siam hemp, Menado hemp, banana fiber, plantain fiber, abaca and white rope is obtained from the so-called tree of *Musa textilis* Luis Née (*M. mindanensis* Rumph),[2] a native of the

---

[1] T. F. HANAUSEK: Realenzyklopädie d. ges. Pharm. 2. Aufl., 8, 481. HANNAN: Textile Fibres of Commerce. London, 1902, 35. v. HÖHNEL: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 65. MATTHEWS: Textile Fibres. New York, 3d Ed. 1913, 435. WIESNER: Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903, 2 372.

[2] The species of *Musa* are giant plants with a subterranean axis, or rhizome, from which arise the leaves with very long sheaths and often long petioles, the latter being usually rolled together so as to form a false trunk often many meters high. (PETERSEN in ENGLER-PRANTL: Pflanzenfamilien, II, 6, 1–7.) *M. sapientum* L. (banana) and its variety *paradisiaca* (plantain) are chiefly valuable for their fruit.

Philippines, where it is also chiefly grown. According to SEMLER[1] the tree is felled, freed from its leaves, and cut into narrow (5–8 cm.) longitudinal strips which, while still fresh, are scraped until the fibers are exposed. The dried and beaten fibers are separated into three grades: (1) *Bandala*, the coarsest and strongest fibers, from the outer part of the trunk; (2) *Lupis*, from the middle layers; and (3) *Tupoz*, the finest and weakest fibers, from the inner portion of the trunk. A single plant yields 0.5 kg. of fibers. Lupis and tupoz serve for making fine native fabrics, while bandala is used for a coarse fabric, *Guimara*, and especially for cordage.[2] Manila hemp makes the best ship cordage.

MICROSCOPIC STRUCTURE.

The coarse fiber is upward of 7 m., the fine 1–2 m., long. It is somewhat stiff, very tough, lustrous, yellowish to brownish white, and mostly so smooth and regular that it may be compared to long horse hair. The commercial fiber consists of bast fibers, parenchyma cells, and a few vessels with 1–2 spiral bands.

The bast cells are 12–40μ broad, mostly 21–30μ, smooth, with rather thin walls, a uniform lumen, the breadth of which is three to four times the thickness of the walls (Fig. 78, *f*, *f′*), and very narrow, sharp ends (*e*). Cross-sections show groups of polygonal cells with rounded corners and a rounded lumen sometimes with contents (*q′*, *i*). Some of the groups consist of cells with thin walls and large lumen, others with relatively thick walls and narrow lumen. Iodine and sulphuric acid color the walls yellow, showing that they are lignified. No outer lamella is evident.

Manila hemp closely resembles New Zealand flax, also pita and sisal hemp, but is distinguished from the first by the character of the lumen and from the last two by the ends of the fibers. Highly characteristic of Manila hemp are the strongly silicified tabular cells, the so-called **Stegmata** (Fig. 78, *s*, *s′*), which surround the fiber bundles for the most part in single rows. After treating a bundle with chromic acid, or burning, the ash shows under the microscope rows of quadrilateral or rectangular stegmata with a hemispherical depression in the upper side of each. At first sight these depressions appear like globular, glassy bodies. If, as recommended by v. HÖHNEL, the fibers are extracted with nitric acid, burned, and treated with dilute acid, the stegmata remain behind, forming what resemble strings of elongated beads.

---

[1] Trop. Agr., **3**, 712. M. SCHANZ: Die Kultur des Manilahanfes auf den Philippinen. Tropenpflanzer, 1902, 175.

[2] A new species of banana (*M. ulugurensis* Warb.) has been recently discovered in German East Africa. Tropenpflanzer, 1904, 116.

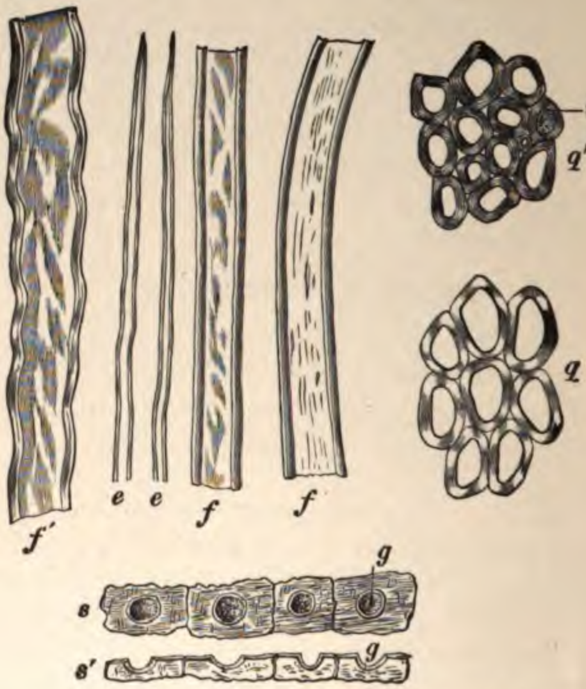


FIG. 78. Manila Hemp. (T. F. HANAUSEK.)

f and *f'* middle part and *e* ends in longitudinal view; *f'* from bruised fiber.—*q* cross-section of group of large fibers and *q'* of small fibers with *i* proteid contents.—*s* surface view of stegmata after incinerating fiber; *s'* side view; *g* depression.

PITA AND SISAL HEMP.[1]

Pita hemp, or pita fiber, also known as Matamoros or Tampico hemp, is obtained chiefly from the leaves of the century plant *Agave Americana* L., although *A. Mexicana* Lam., *A. vivipara* L., and other species of the genus are said to furnish a certain amount of the fiber of commerce. Mexico is the center of the pita industry.

---

[1] T. F. HANAUSEK: Realenzyklopädie d. ges. Pharm. 2. Aufl., **10**, 313. HANNAN: Textile Fibres of Commerce. London, 1902, 60. V. HÖHNEL: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 66. MATTHEWS: Textile Fibres. New York, 3d Ed. 1913. 439, 444. WIESNER: Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903, **2**, 375, 378, 382.

Sisal hemp, hemp grass, Mexican grass, or silk grass is obtained from species of *Agave* grown in Yucatan and the West Indies. According to **Semler** the natives cultivate seven different species of this genus, of which Chelem (*A. Sisalana* Mill.), Yaschki (*Agave sp.*), and Sacci are the most important, while Cajun, or Cajum (*Fourcroya Cubensis* Jacq. and *F. gigantea* Vent.) yield only coarse fibers. **Gürke**,[1] however, has shown that *Agave rigida* and its variety *sisalana*, also *A. elongata*, yield true sisal hemp, while *Fourcroya gigantea* (*F. fœtida*) yields Maritius hemp, which previously was regarded as a product of certain species of *Aloë*.

In commerce there appears to be no sharp distinction between pita and sisal hemp, although the marked differences between fine and coarse grades of *Agave* fibers are recognized.

MICROSCOPIC STRUCTURE.

Microscopic investigations have shown that the fibers of the different species of *Agave* are practically the same in structure.

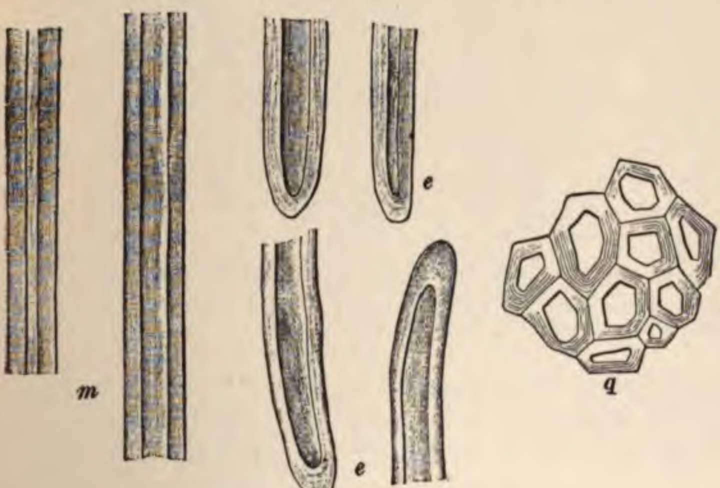


Fig. 79. Pita Hemp from *Agave Americana*. (T. F. **Hanausek.**)
m middle pieces; *e* ends; *q* cross-section.

The technical fiber is yellow white or white and consists of fiber cells, large spiral vessels, and parenchyma cells containing single oxalate crystals up to 0.5 mm. long. The cells of the parenchyma are mostly destroyed and the glittering crystals or pieces of crystals are left deposited in longitudinal rows on the fibers, thus furnishing a highly characteristic means of identification. On the coarse fibers used for making brushes these crystals may often be seen with the naked eye.

---

[1] Notizbl. k. Bot. Gartens. Berlin, 1896, No. 4.

The sclerenchymatized fiber cells of pita hemp (Fig. 79) are very uniform in structure. As a rule the walls are thin, the lumen is broad, and the ends are blunt and broad, seldom forked, often strikingly thickened. They are 17–28μ broad, mostly 22–23μ, and strongly sclerenchymatized. Iodine and sulphuric acid color the walls brown yellow. The closely united individuals of the groups are sharply polygonal, with a large rounded polygonal lumen. An outer lamella is not evident, and stegmata are entirely lacking. Cross-fissures are found on some of the fibers. Short thick-walled fibers with short-pointed ends are present in pita hemp and apparently in still greater numbers in sisal hemp (Fig. 80). These have a narrow lumen and distinct pores. All the *Agave* fibers contain fiber cells and crystals like those shown in Fig. 80.

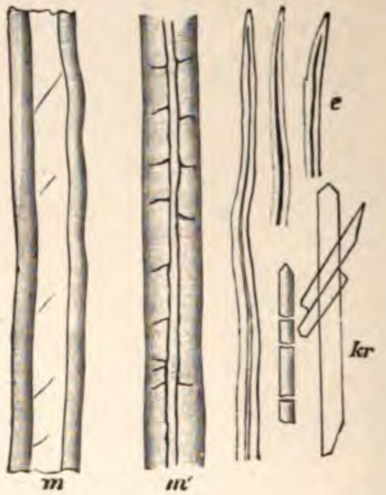


FIG. 80. Sisal Hemp in Longitudinal View. (T. F. HANAUSEK.)
m middle part of a long fiber with broad lumen, *m'* of a short fiber with narrow lumen; *e* ends; *kr* whole and broken crystals of calcium oxalate.

Pita and sisal hemp serve as inferior substitutes for Manila hemp in the manufacture of cordage, also for making brushes and paper pulp, and, colored, as a substitute for fine horse hair, which it closely resembles.

NEW ZEALAND FLAX.[1]

This fiber is obtained from the leaves of the flax lily (***Phormium tenax*** Forst.), a native of New Zealand and Norfolk Island, where it is chiefly cultivated. It is also grown in California and some other regions. The crude fiber resembles Manila hemp; it consists in large part of sclerenchymatized fiber bundles and, as noted by BARRESWILLE, usually, but not always, becomes red with fuming nitric acid. In the leaf the

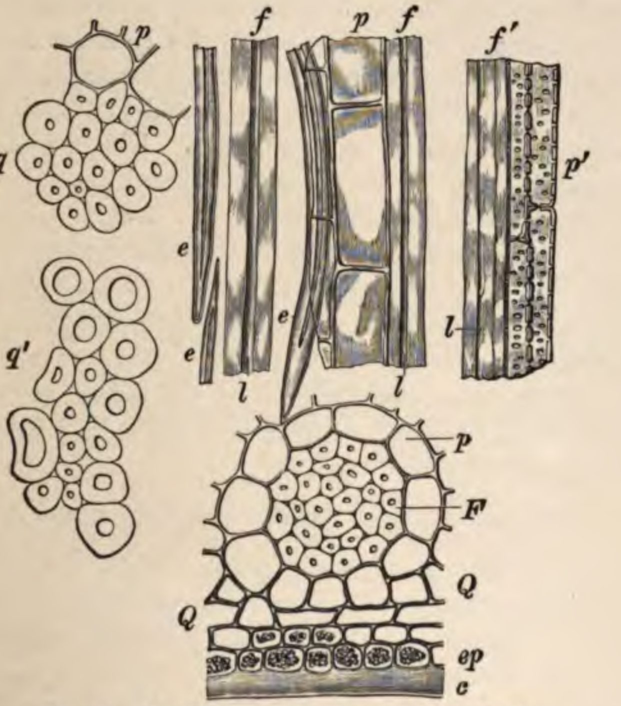


FIG. 81. New Zealand Flax. (T. F. HANAUSEK.)

f pieces of fibers of the sclerenchyma bundles; *p* parenchyma surrounding the last; *f′* fibers of the vascular bundles; *e* ends of fibers; *p′* porous elements of the vascular bundles.—*q* cross-section of the bast-fiber bundles; *q′* cross-section of the bast fibers of the vascular bundles.—*Q* cross-section of a bast-fiber bundle with accompanying elements: *ep* epidermis with *c* cuticle; *F* bundle proper; *p* parenchyma.

---

[1] T. F. HANAUSEK: Realenzyklopädie d. ges. Pharm. 2. Aufl., **9**, 365. HANNAN: Textile Fibres of Commerce. London, 1902, 39. V. HÖHNEL: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 64. MATTHEWS: Textile Fibres. New York. 3d Ed. 1913. 43c

229629B

fiber bundles are distributed through a ground tissue of parenchyma cells, the whole being covered by a strongly cuticularized epidermis of nearly rectangular, brittle, lustrous cells (Fig. 81, *Q*). As may be seen in cross-section (*q*, *p*) and longitudinal view (*f*, *p*), fragments of the parenchyma and even of the epidermis are often attached to the commercial fiber. The fiber cells are smooth, 10–18μ, usually 16μ, broad. Striations, knots, and dislocations are lacking. The lumen (*f*) is usually much thinner than the walls and is apparently empty; the ends are mostly pointed (rarely blunt), strongly thickened, or with no lumen at all. In cross-section the closely united fiber cells are round or rounded polygonal, with a very small circular or oval lumen. Thin-walled fibers with broad lumen (*q′*), also porous elongated parenchyma cells (*f′*, *p′*), are sometimes found accompanying thick-walled forms. These are from the bast of the fibro-vascular bundles which lie inside of the zone in which are distributed the isolated bast-fiber bundles. Since vessels occur only in connection with these fibers it is evident that they are seldom found in the commercial product.

New Zealand flax is very similar to aloe fiber (Mauritius hemp, p. 97) and bow-string hemp (species of *Sansevieria*); these, however, are polygonal in cross-section.

III. MICROSCOPIC EXAMINATION OF PAPER.[1]

Paper, in the strict sense, is a thin felt of finely divided fibers, used chiefly for writing, printing, and wrapping purposes, but in a broader sense it includes pasteboard, papier-maché, and the hard fibrous composition from which are made pails and other common utensils.

The best materials for paper manufacture are rags of linen, cotton, hemp, and other vegetable fibers. Linen rags make the finest and whitest paper; that made from unused linen and hemp is stronger, but the color is not pure white and the cost of the product is for most purposes prohibitive.

---

[1] CROSS and BEVAN: A Text-book of Paper-making. London, 1900. GRIFFEN and LITTLE: The Chemistry of Paper-making. New York, 1894. HANNAN: Textile Fibres of Commerce. London, 1902, 125. W. HERZBERG: Mikrosk. Untersuchung des Papieres, Mittheil. k. Tech. Vers. Anst. Berlin, 1887, **5**, Ergänzungsheft 3, 1. *Idem:* Papierprüfung. Berlin, 3. Aufl. 1907. V. HÖHNEL: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 98. HOYER: Das Papier, seine Beschaffenheit und deren Prüfung. München, 1882. E. KIRCHNER: Das Papier, I. Theil. Die Geschichte der Papierindustrie und Allgemeines über Papier. Herausgegeben vom Verleger des Günther-Staib'schen Wochenblattes für Papierfabrication in Biberach. 1897. SINDALL: An Elementary Manual of Paper Technology. Philadelphia, 1906. WIESNER: Die Mikroskopische Untersuchung des Papieres mit besonderer Berücksichtigung der ältesten oriental. und europ. Papiere. Mittheilungen aus der Sammlung des Papyrus Erzherzog Rainer. Wien, 1887, **2** u. **3**. WHITNEY and WOODMAN: The Microscopic Examination of Paper Fibres. Technol. Quart. 1902, **15**, 272.

Paper of the best quality must be durable in the sense that it is not affected by long-continued exposure to the atmosphere, and if it turns yellow with time, at least it does not take on a brown, scorched color and does not become brittle. Such paper can only be made from fibers which, even in their original condition, consist of nearly pure cellulose. If it gives reactions for substances other than pure cellulose, and especially if it contains lignin—that is, lignified fibers—the paper must be of inferior durability.

Lignin.

Little is known as to the chemical constitution of lignin, the characteristic constituent of woody materials.[1] It is probably a mixture of different chemical substances, two of which, according to the investigations of v. HÖHNEL[2] and MAX SINGER,[3] are **Coniferin** and **Vanillin**.[4] G. LANGE has described two lignin acids, and more recently CZAPEK[5] has found a process for isolating the substance that gives the reaction for lignin. These reactions include the yellow, green, violet, blue, or red colors produced by certain phenols in conjunction with mineral acid and the yellow color produced by neutral or acid solutions of aromatic amines. For example, phloroglucin and hydrochloric acid, pyrrol and hydrochloric acid, and indol and sulphuric acid give a cherry-red; phenol and concentrated hydrochloric acid, green or blue; thymol and hydrochloric acid and a little potassium chlorate, blue; anilin sulphate, or chloride, on the other hand, gives a lemon yellow. In some cases the lignified elements of fruits (e.g., coffee) or barks give a red color with concentrated hydrochloric acid alone, from which it is inferred that the organs themselves contain phloroglucin.

---

[1] See TSCHIRCH: Angewandte Pflanzenanatomie, 1889, 174. ZIMMERMANN: Die Morphologie und Physiologie der Pflanzenzelle, 1887, 124.

[2] Histochemische Untersuchungen über das Xylophilin und das Coniferin. Sitzb. Wien. Akad., **67**, I, 663.

[3] Beiträge zur näheren Kenntniss der Holzsubstanz, etc. Ebenda, **85**, I, 345. See also ROB-HEGLER: Histochemische Untersuchungen verholzter Membranen. Marburg, 1890.

[4] Coniferin is a glucoside, of which vanillin (methyl protocatechuic aldehyde) is a decomposition product. (HUSEMANN: Pflanzenstoffe. Berlin, 2. Aufl. 1882, 338.)

[5] Ueber die sog. Ligninreactionen des Holzes. Ztschr. Physiol. Chem. 1899, **27**, 141–166.

Czapek has pointed out that the so-called lignin reagents do not explain at all the chemical nature of lignin, since phloroglucin and hydrochloric acid give a red color with certain phenols (eugenol, safrol, anethol), alcohols (styrole, coniferylalcohol, syringenin), aldehydes, and acids (caffeic acid, ferulic acid). The process employed by **Czapek** for isolating the substances of lignified tissues which give the reaction in question is as follows: Wood filings are boiled some minutes with zinc chloride solution and treated after cooling with phloroglucin and hydrochloric acid, after which not only the wood but also the supernatant liquid is colored red. On shaking the material after treatment with zinc chloride, with ether or benzol, the extract also responds to the phloroglucin test, showing that the chromogenic substance was split off by zinc chloride and dissolved in the ether or benzol. Cold saturated sodium bisulphate solution also acts in a similar manner. From 1 kg. of wood may be obtained a very small amount of a substance which **Czapek** designates **Hadromal**, after hadrome (see p. 259). The lignin reactions are probably due to a compound of hadromal, which may be a hadromal cellulose ester. According to the investigations of **Faber**,[1] the above are merely group reactions[2] and the phloroglucin reaction merely indicates the presence of hadromal in cellulose and shows nothing as to the lignification. The best and surest test for lignification is that devised by **Maule**,[3] as follows: Sections are soaked for about five minutes in one per cent potassium permanganate solution, and after washing in water are soaked for 2–3 minutes in dilute hydrochloric acid, and finally in ammonia. All lignified parts take on a red color by this treatment.

Lignified membranes treated with hydroxylamin, as described by **Seliwanoff**,[4] do not give the phloroglucin reaction.

Tests for Lignin.—As a preliminary test, paper should be examined for lignified fibers. If no cherry-red color is produced by phloroglucin and hydrochloric acid, it may be concluded that wood pulp, jute, and similar lignified fibers are absent. It should not be forgotten, however, that sugar in the paper gives a color reaction, and it is always necessary to wash the paper thoroughly before testing. It has been shown by v. **Höhnel**[5] that if Swedish filter paper consisting of pure cellulose is soaked in a solution of cane sugar and treated after drying with phloroglucin and hydrochloric acid, no color appears immediately, but on drying the paper takes on an intense red color like that formed in the presence of lignified fiber. Wood cellulose containing traces of lignin also gives a deep-red color if after treatment with phloroglucin and hydrochloric acid it is quickly dried at 100–110° C. It is therefore clear that a preliminary test for lignin can not take the place of microscopic examination.

---

[1] Ber. Deutsch. Bot. Gesell 1904, **22**, 177.

[2] Note the reaction of paper impregnated with cane sugar given under Tests for Lignin.

[3] Beitr. Wiss. Bot. 1900, **4**, 166.

[4] Bot. Centbl. 1891, **45**, 279.

[5] Ueber die Holzstoffreaction bei der Papierprüfung. Centorg. Warenk. Technol. 1891, **5**, 219–221.

Sizing.

Tests to determine the nature of the sizing may next be undertaken. Only three kinds of sizing need be considered, namely, with glue, with starch, and with resin compounds.

Glue Sizing.—For detecting glue, treatment with Millon's reagent is commonly sufficient. Pure gelatin does not respond to this test, but the commercial glue used in paper always contains traces of proteid matter which give a rose-red or brick-red color on heating with the reagent. In applying this test it should not be forgotten that proteids may be present as contents of vegetable cells, or as gluten or other impurity of starch used in sizing.

Starch Sizing may usually be detected with ease and certainty by iodine solution. If ferment organisms are present the blue color does not appear until after they have been killed by a short treatment with hydrochloric acid. Vegetable parchment always gives a blue color with iodine, since the membrane of the fibers has been converted into amyloid, which reacts similar to starch.

Resin Sizing, or sizing with aluminum resinates, is most commonly practiced.[1]

In rosin-sized paper free resin is always still present, on which fact are based the methods of detection described by WIESNER and MOLISCH. If proteids, resins, and fats are treated with sugar solution and sulphuric acid, these substances take on an intense red-violet coloration (Raspail's reaction). All resin-sized paper gives this reaction. Oftentimes the simple addition to the paper of a drop of sulphuric acid gives the violet color. The process described is not suited for the examination of wood-pulp paper, since this becomes a dirty dark green on addition of strong sulphuric acid.

---

[1] Vegetable glue is prepared by heating common rosin with crystallized soda. If less soda than is necessary for complete saponification of the resin is used, a milky liquid containing finely divided resin in suspension, the so-called *white glue*, is obtained; if, however, enough soda for complete saponification is used, a clear neutral resin soap, or *brown glue*, is formed. If alum is added to white glue, free resin and aluminum resinate are separated. It is probable that it is the free resin that acts as a size, since the sizing is not effected in the machine into which the resin is poured, but on the drying rolls of the paper machine where the resin melts, spreads among the fibers, and binds them together.

The method for the detection of resin sizing formerly most commonly employed depends on the insolubility of the resin in water. If an alcoholic solution of resin is diluted with considerable water, the liquid becomes milky owing to the separation of the resin.

Herzberg's Method[1] is a simple and apparently reliable means of detecting resin sizing. If a drop of ether is dropped on a piece of resin-sized paper and allowed to evaporate, on holding the paper to the light there appears, about the place wet by the ether, a translucent ring due to resin deposited in vitreous form from the ether. In paper sized with pure animal glue no ring is evident, while in paper sized with a mixture of vegetable and animal glue the ring is less distinct.

A certain amount of starch is always used in resin sizing to make the liquid more viscous and hinder the formation of large resin drops. For this reason the presence of starch sizing should never be affirmed until resin has been proved to be absent and the amount of starch has been found relatively large.

Identification of Fibers.

The microscopic identification of paper fibers is a most difficult investigation.[2] The chemical and mechanical treatment to which the fibers are subjected during manufacture partially disorganizes them and, as is evident from the cuts on the subsequent pages, greatly alters their microscopic appearance.

In order to facilitate the work of identification several schemes have been employed for separating the fibers into more or less distinct groups. Some of the most important of these schemes depend on the absorptive capacity for color reagents and especially for iodine.

Herzberg's Test.—This author has grouped the most important paper materials, according to the color (if any) with iodine, into the following three classes:

---

[1] Ueber eine einfache Methode zum Nachweis der Harzleimung im Papier. Mittheil. Mech. Tech. Vers. Ans. Charlottenburg, 1892, 80.

[2] An excellent compilation of the methods of examination will be found in HERZBERG'S paper, "Der heutige Stand der Papierprüfung." Sonderabdruck. Papier-Ztg. Berlin, 1892.

I. Fibers colored yellow: mechanical wood pulp, jute.

II. Fibers not colored: wood cellulose, straw cellulose, esparto cellulose.

III. Fibers colored brown: cotton, linen, hemp.

In many cases these color reactions are indecisive and it is impracticable to separate the fibers sharply into groups. A much more accurate and practicable system of classification is that based by v. HÖHNEL[1] on the cellulose reaction with iodine and sulphuric acid.

v. Höhnel's Test.—The following description is in v. HÖHNEL'S own words (translated):

"The most important detail is the concentration of the sulphuric acid. This is best determined by practical experiment as follows: Fibers from white cotton and linen rags, also shreds of white wood cellulose and white straw cellulose (or a piece of white paper containing these four fibers), are boiled in a small beaker for some minutes with 1–5% potassium hydrate and washed with water. Very small quantities of the four fiber materials thus prepared are placed side by side on a slide, thoroughly dried by pressing twice with a piece of blotting paper (which also causes the fibers to adhere to the slide), and completely covered with a drop of a solution of iodine in potassium iodide of such a strength that a layer 3 cm. thick is ruby red, but at the same time distinctly transparent. After 1–2 minutes the iodine solution is removed by pressing twice with blotting paper so that only that absorbed by the fibers remains.

"If any of the iodine solution remains between the fibers, the results of the test will be indecisive or entirely worthless. It is also important that there are no knots in the fibers and that they are not in bundles. The individual fibers must be carefully separated from one another with a needle so that the two reagents will act uniformly and each fiber will give a decisive reaction. If in spite of precautions there are knots or bundles into which the reagents do not penetrate these must be disregarded and only the appearance of the isolated fibers observed.

"The four kinds of fibers, each impregnated with iodine, are next covered with a drop of diluted sulphuric acid and the cover glass is placed on them.

"The results obtained vary greatly according to the strength of the

---

[1] Ueber eine neue Methode der mikroskop. Papierprüfung. Mittheil. k. k. Tech. Gewerbe-Museums, Sect. f. chem. Gewerbe, Aprilheft 1889, 6–8.

It should here be noted that there will be found, in microscopic mounts of most papers, fragments so greatly mutilated that they cannot be identified, at least with certainty. In such cases the "paper sulphuric acid" test may be applied. After some practice the microscopist will be able to identify many of the very short pieces.

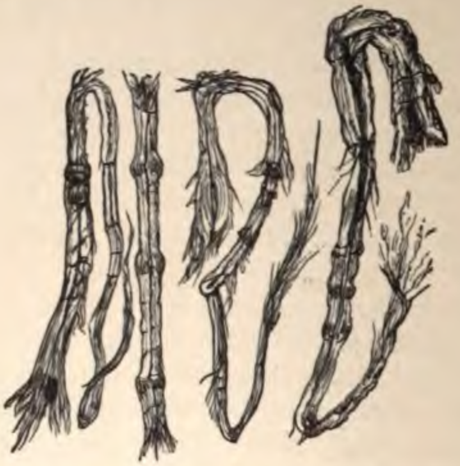


FIG. 82. Flax Bast Fibers from Linen-rag Writing-paper. (T. F. HANAUSEK.) The fibers are much bruised and have fringed ends.

2. **HEMP PAPER.**—Particularly tough and durable paper (e.g., for bank notes) is made directly from hemp tow. In such paper well-preserved hemp fibers and here and there uninjured ends (see Fig. 65) may often be found. The coarse sorts also contain numerous fragments of the accompanying elements, such as tube cells and epidermal cells. The bast fibers in paper made from hemp rags are usually so greatly altered that they can not be distinguished from those of linen paper. The ends of the fragments are strikingly fringed. v. HÖHNEL states that the fibrils of this fringe are shorter than in linen paper, since hemp is more brittle than flax. Knotty dislocations (Fig. 83) occur at frequent intervals, and are of such a nature that the fiber in many places shows a wavy structure. The longitudinal striations interrupted by numerous fissures, also longitudinally arranged, are so strongly developed that the outline of the lumen is no longer evident. Under some circumstances it is not possible to distinguish hemp and linen fibers in paper, especially if, as is usually the case, several kinds of fibers are present. Hemp fiber is seldom found in white paper, which is the kind most often examined.

3. **COTTON-RAG PAPER** is in most cases easily recognized. It should be remembered, however, that a certain amount of linen rags or other cellulose fibers are commonly used in its preparation and, as a consequence, linen as well as cotton fibers will be found on microscopic examination. The broad strap-shaped hairs of cotton (Fig. 84), with smooth, or only slightly fringed, ends and distinct lumen, distinguish them from the fibers of linen and hemp. Here and there the hairs show distinct twists similar to those of an auger. Sometimes, owing to pressure, the lumen is narrow like that of a bast fiber. **HERZBERG** calls attention to numerous characteristic crossing systems of striations (x). Similar lattice-like markings occur in wood fibers.

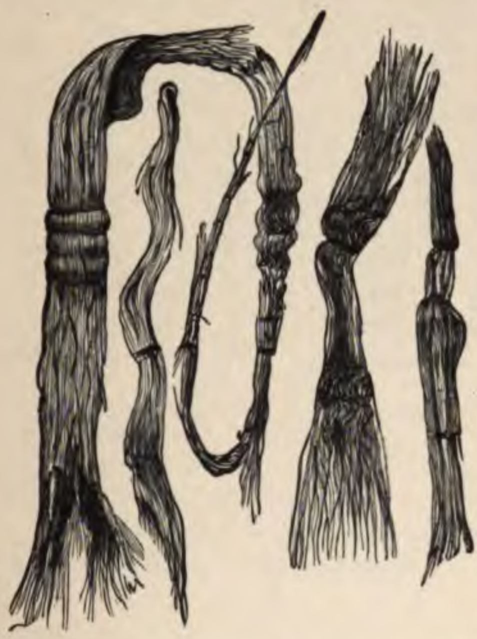


FIG. 83. Hemp Fibers from Heavy but Fine Packing-paper. (T. F. HANAUSEK.)
All of the fibers are mutilated and one shows a forked end.

4. **JUTE PAPER** is used chiefly for envelopes and wrapping. The so-called Manila paper is made chiefly of this material. Commonly jute paper contains well-preserved bast-fiber bundles, the individuals of which after isolation show the characteristic smooth walls free of striations and the irregular and sometimes interrupted lumen (Fig. 68). Fibers of unbleached jute give the lignin reaction.

5. **STRAW CELLULOSE PAPER.**—Most papers at the present time contain this raw material, which is made from wheat or rye straw. The latter is most commonly employed, although wheat straw, owing to its low silica content (4.3 per cent), yields an excellent product. Chinese straw paper is made from rice straw. Maize husk and esparto are also valuable raw materials.

Wheat- or Rye-straw Cellulose contains very regular, strongly thickened sclerenchyma fibers (Fig. 85, *b*) with pointed or forked ends and often knotty thickenings. In addition the material contains numerous elements of the epidermis, the fibro-vascular bundles, and the parenchyma, all of which are excellent guides in diagnosis. The epidermal cells are partly short and partly long, both forms having very sinuous walls (*e*), and are often associated with stomata (*sp*). Large pitted vessels (*g*), detached rings (*r*) of annular vessels, narrow tracheids (*tr*), spiral vessels (*g'*) with loosely wound spirals, and enormous, rounded or elongated, wrinkled, bladder-like parenchyma cells may be found in abundance.

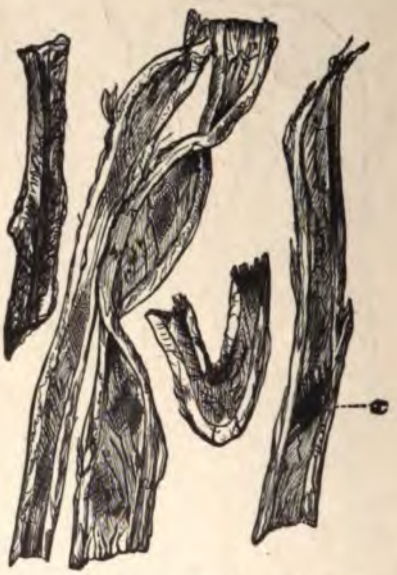


FIG. 84. Fibers from Cotton Paper. (T. F. HANAUSEK.)

In the middle, pieces of quite well-preserved cotton fibers from a filter-paper; at the left, a piece much like a linen bast fiber; at the right, a piece resembling a broad wood fiber with lattice-like markings at *x*.

Esparto Cellulose is similar to true straw cellulose. This material, known also as alfa fiber, is obtained from the leaves of two grasses, *Stipa* *tenacissima* L. (*Macrochloa tenacissima* Kunth) and *Lygeum Spartum* L. The former yields true esparto,[1] the latter esparto basto.[2]

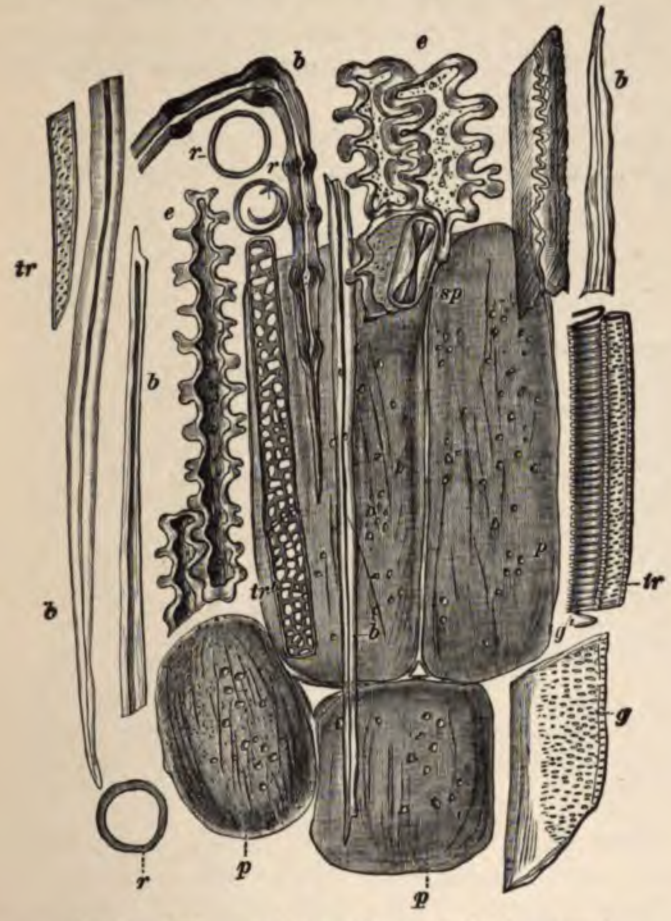


FIG. 85. Elements of Straw Pulp. (T. F. HANAUSEK.)

b sclerenchyma fibers; *e* epidermal cells with *sp* stomata; *g* fragment of pitted vessel; *r* ring separated from an annular vessel; *g'* spiral vessel; *tr* and *tr'* narrow tracheids with short joints; *p* parenchyma cells.

Esparto fibers from *Stipa tenacissima* can be readily identified by the sclerenchyma fibers (Fig. 86, *m* and *e*), the epidermis with short cells

---

[1] The leaves cut in suitable lengths furnish the removable straws of the stogies known in Austria-Hungary as "*Virginia-Cigarre*".

[2] A paper material similar to esparto, known in India as bulbous or Bhabur-grass, according to STAPF (Bull. Misc. Inform. 1894, No. 94, 367), is obtained from *Ischæmum angustifolium* Hook, order *Gramineæ*.

(*o* and *k*), and especially the short, mostly hooked, strongly thickened bristle-like hairs (*h*). *Large parenchyma cells are not present.* Care should be taken not to mistake short straight bristles for end fragments of fibers. The former are characterized by the abruptly enlarged base in which the lumen is also usually enlarged whereas in the remainder of the hair it is a mere line.

Esparto fibers from *Lygeum Spartum*[1] are distinguished chiefly by the hairs, which are mostly straight, blunt, and are broader and have broader lumens than those of *Stipa*. The bast fibers also differ from those of *Stipa* in that they are lignified and have broader lumens.

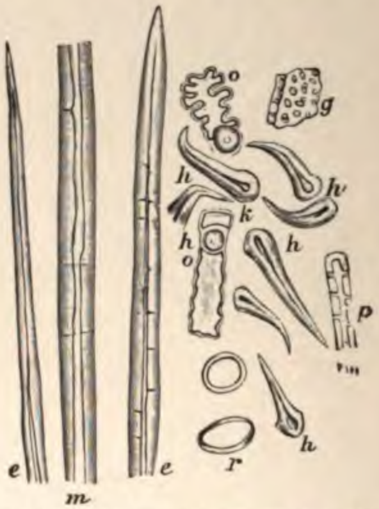


FIG. 86. Esparto Cellulose from *Stipa tenacissima*. (T. F. HANAUSEK.)
m middle part of bast fibers; *e* ends of bast fibers; *o* epidermal cells with *k* short cells and *h* scar of bristle; *g* fragment of pitted vessel; *p* porous cell; *h* bristles.

The Husks of Maize or Indian Corn consist of the papery sheath-like leaves which envelop the ear. Their numerous fibers make them especially adapted for paper manufacture[2] Paper made from this material is not easily distinguished from that made from the straw of other cereals, still the epidermal cells and the parenchyma, as well as the fibers, show some marked characteristics of value in diagnosis. The sclerenchyma fibers (Fig. 87, *f* and *f′*) are lignified, up to 80μ broad, the breadth of the lumen almost always exceeding the thickness of the walls. Especially striking are the diagonal, spirally arranged, cleft-like pores. The ends of the fibers are strongly thickened, blunt, entire, or with two or more points, or else, according to WIESNER, with antler-like branches. Joints of tracheids (*g′*), fragments of vessels (*g*) with numerous pores, and porous parenchyma cells (*p*) occur in abundance. Strongly silicified epidermal cells from the lower surface of the leaf (*e′*), firmly united with sclerenchyma elements, often occur in large plates in the paper. The epidermis from the upper side (*e*) contains large porous cells with irregularly sinuous walls which

---

[1] HALACZY: Österr. Bot. Ztg. 1901.

[2] T. F. HANAUSEK: Realenzyklopädie d. ges. Pharm. 2. Aufl., **10**, 22. AUER V. WELSBACH: Die Verarbeitung der Maispflanze. Wien, 1862. WIESNER: Mikroskopische Untersuchung der Maisliesche und der Maisfaserproducte. Dingler's Polyt. Jour. 1865, **175**, 225. *Idem:* Technische Mikroskopie, 1867, 226, and Rohstoffe, 1873, 450. Maize stalks are also used for paper manufacture.

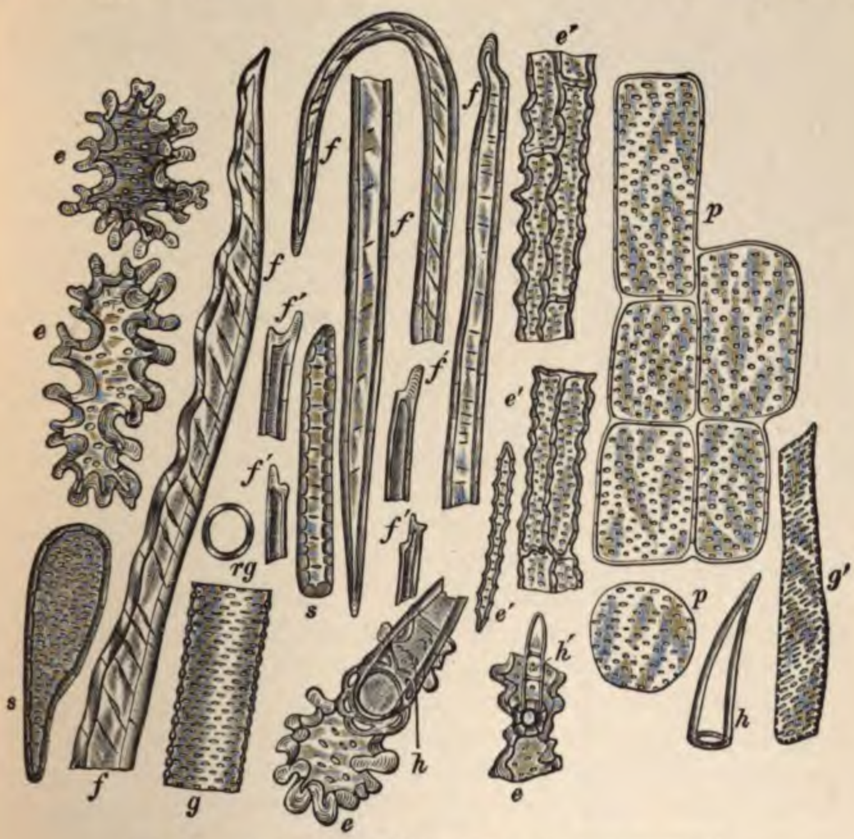


FIG. 87. Paper Pulp from Maize Husk. (T. F. HANAUSEK.)

e upper epidermal cells; *e′* lower epidermal cells; *f* sclerenchyma fibers; *f′* forked ends of fibers; *g* and *g′* fragments of pitted vessels; *rg* ring of an annular vessel; *s* sclerenchyma cells; *p* parenchyma cells; *h* unicellular bristle; *h′* 3-celled hair.

are strongly thickened at the bends. Several forms of hairs are prese (1) short three-celled thin-walled hairs (h'); (2) short, strongly thi ened bristle-like forms with broad lume and (3) hairs similar to the last but mu longer, the broad bases of which are su deeper than the epidermal cells (Fig. 87 *h*; Fig. 88, *h*), and are surrounded by circle of small accompanying cells eleva above the surface of the organ so as form a hump. In case the hair has fall the scar is evident as a round holl Characteristic silica skeletons of the e dermal cells may be found in the ash.[1]

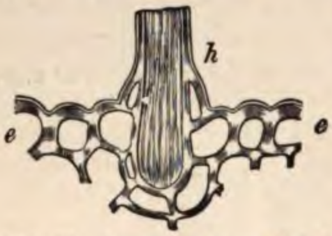


FIG. 88. Base of a Long Unicellular Bristle-hair of Maize Husk. (T. F. HANAUSEK.)
e epidermal cells; adjoining the hair are small cells of the rosette.

Millet Straw.—Recently paper has been made in France from mi straw (Fig. 89). The fiber cells are scarcely distinguishable from th of other kinds of straw; the ends likewise often have short irregular fo or branches (*b*). A very interesting form worthy of a detailed investi tion is shown in $b_{,,}$. The outer layer of this fiber was in places separa from the normal inner layer and wrinkled. Whether the inner layer is tertiary membrane, or whether still other layers are attached to it, can be determined from the evidence at hand. Broad bast fibers (b') with locations remind us of hemp fibers. The epidermal cells of the st (*ep*, *e*) and leaf show the well-known structure characteristic of the *G mineæ;* subepidermal cells (*s*) with rounded excrescences (first noted v. HÖHNEL), spiral vessels, detached spiral thickenings, and rings fr vessels, as might be expected, are also found in abundance; typical la thin-walled parenchyma cells apparently containing only air are also p ent. In addition to these elements we find groups of almost cubical or p allelopipedal strikingly thick-walled cells, each containing an appare corroded oxalate rosette ($p_{,}$), a form of tissue which the writer has n found in other kinds of straw. As must be the case with a specie *Panicum*, there is an abundance of trichomes, of which commonly th forms are distinguishable: (1) straight, pointed, strongly thickened bris of different lengths with swollen bases (*h*); (2) hooked bristles with v large bases forming the very fine saw edges of the leaves and resembl closely the hooked bristles of esparto, but larger; (3) straight, giant bris (h') over 300μ long, with strongly thickened walls, which are distribu at regular intervals over the leaf surface, their bases being mostly inserted in a thin colorless sheath. These giant bristles are highly characteristic of millet straw.

---

[1] WIESNER: Rohstoffe des Pflanzenreiches. Leipzig. 2. Aufl. 1903, **2**, Fig. 21.

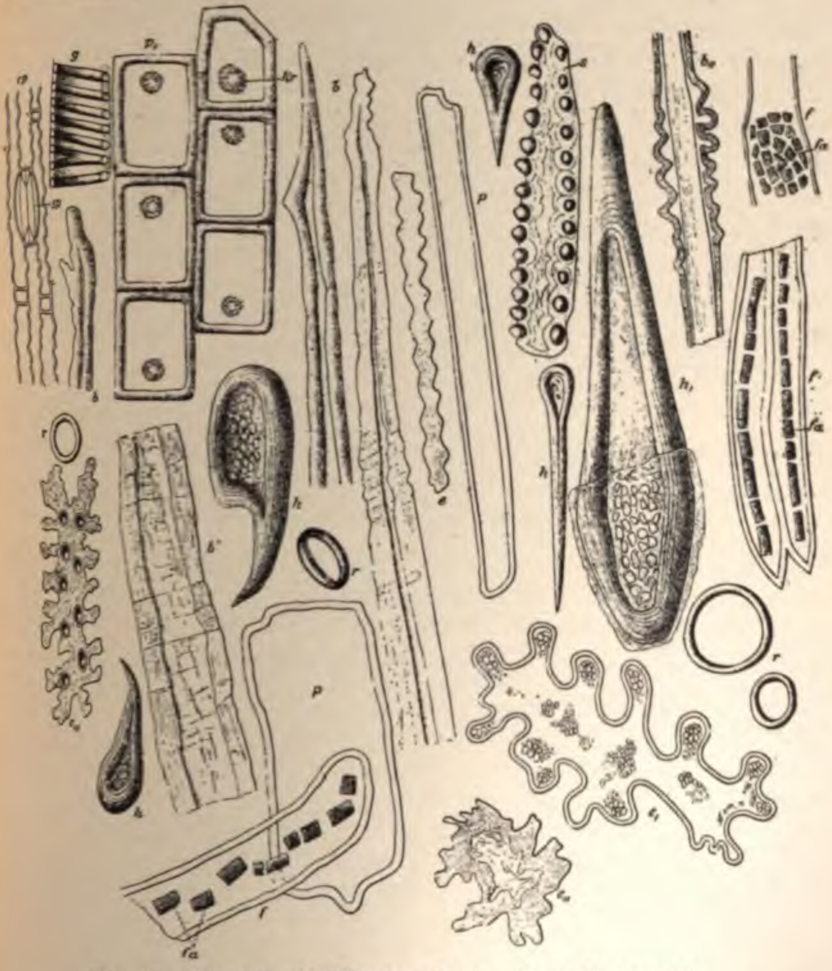


FIG. 89. Elements of Millet-straw Paper. (T. F. HANAUSEK.)

b bast-fiber ends; *b′* middle piece of a broad bast fiber with hemp-like dislocations; *b,,* fragment of bast fiber with separated and wrinkled outer layer; *ep* epidermis of stem with *sp* stoma; *e* isolated epidermal cell; *e,* epidermal cell from leaf with groups of shining bodies; *e,,* strongly silicified short cell of the epidermis; *e,,,* epidermal cell from beneath with holes; *s* sub-epidermal cell with warts; *h* bristles from the edge of the leaf; *h,* large, straight bristle (300μ long, in the broadest part 69μ broad) with base in a kind of socket; *g* spiral vessel; *r* ring separated from annular vessel; *f* pigment cells with crystal-like fragments of the hard, red-brown pigment *fa*; *p* large, thin-walled parenchyma cells; *p,* united, thick-walled, almost cubical parenchyma cells, each with an oxalate rosette.

Among the most valuable histological elements are the tube-like bodies—apparently long, pointed prosenchyma cells—containing in their original condition a red-brown elongated mass which, however, during treatment breaks up into angular crystal-like pieces (*f*, *fa*). These cells occur in more or less abundance in the paper. The angular contents are unquestionably of a material resembling phlobaphane, although at first sight they might be mistaken for crystals. It is well known that the straw of millet is often streaked or spotted.

Millet-straw paper is distinguished from other straw papers by the large hooked hairs, the giant hairs, and the tube cells with colored contents. Naturally there are other distinctions, but these need not concern the technical microscopist.

6. **MECHANICAL WOOD PULP.**[1]—The most important raw materials are coniferous woods (e.g., fir, spruce, and pine), all of which are characterized by tracheids with bordered pits on the radial surface.[2] The chief elements of paper made from this pulp are small groups of tracheids crossed

---

[1] See chapter on Woods (pp. 174–243). Also HERZBERG: Die Sicherheit der qualitativen Holzschliffbestimmung. Mittheil. Tech. Vers. Ans. zu Berlin, 1890, 132. *Idem:* Ueber die Schätzung des Holzschliffs in Papier. *Ibid.*, 1891, 44. LITSCHAUER: Ueber die Festellung des Mengenverhältnisses der Fasern im Papier. Centbl. Österr. Papierindus. 1905, Nos. 1, 2, 3.

[2] The following table shows the kinds and amounts of wood manufactured into pulp by various processes in the United States in 1905. (H. M. HALE: Wood Used for Pulp in 1905. U. S. Dept. Agr., Forest Service, Circ. 44.)

Kind.	Process.								
	Mechanical.		Sulphite.		Soda.		Total.		Per Cent.
	Cords.		*Cords.*		*Cords.*		*Cords.*		
Spruce:									
Domestic.	794,260		784,674		71,775		1,650,709		
Imported.	230,289		392,256		....		622,545		
		1,024,549		1,176,930		71,775		2,273,254	71.2
Poplar:									
Domestic.	8,592		....		290,583		299,175		
Imported.	2,800		....		20,083		22,883		
		11,392		....		310,666		322,058	10.1
Hemlock...		30,843		344,579	....			375,422	11.8
Pine.......		14,432		18,600		24,367		57,399	1.8
Balsam....		10,801		45,943	....			56,744	1.8
Cottonwood	....		....			10,507		10,507	.3
All other...		4,777		44,341		47,621		96,739	3.0
		1,096,794		1,630,393		464,936		3,192,222	100.0

H. STANLEY BRISTOL, of the U. S. Dept. Agr., Forest Service, is at present carrying on extensive investigations on the utilization for wood pulp of other American woods and various wood by-products. (A. L. W.)

by fragments of the medullary rays, the latter being of value in determining the species. At the ends, the wood cells are often extended into points. The lignin reaction, as well as v. Höhnel's test, is of service in estimating the amount of mechanical wood pulp in a given sample. Newspaper paper and the better grades of wrapping-paper must contain a certain amount of linen or cotton stock, or else cellulose, which serves as binding material.

In careful microscopic examination it is usually possible to distinguish the three principal coniferous woods—spruce, fir, and pine. Elements of fir wood are shown in Fig. 90. The distinguishing characteristic is the presence of simple pits in the cells of the medullary rays. In spruce the pits are bordered; they are also smaller and less distinct. The communication between the tracheids and the medullary rays in fir wood is by means of numerous small pores, not by large-bordered pits such as occur between the tracheids.[1]

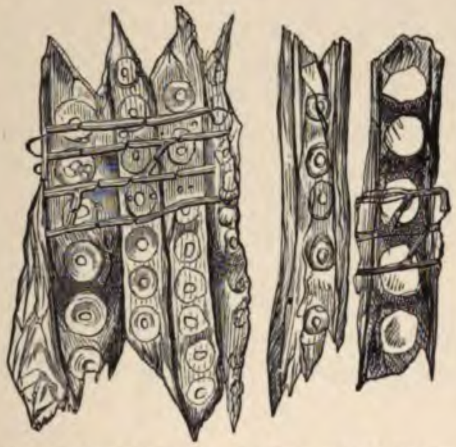


Fig. 90. Pulp of Coniferous Wood. (T. F. Hanausek.)

The identification of pine wood is much easier than the distinction of fir from spruce. The cells of the medullary rays in the outer layers have irregular tooth-like thickenings often found in paper, while those of the inner layers have pits in the form of large holes.

Wood elements from the poplar, birch, and locust are easily distinguished from coniferous woods by the libriform fibers and the vessels with numerous pits. Individual species of angiospermous or broad-leaved woods can be identified only after a systematic study of the structure of each (see chapter on woods, pp. 196, 211).

---

[1] In Fig. 90 large bordered pits are erroneously shown back of the medullary cells.

7. **WOOD CELLULOSE**, or **CHEMICAL WOOD PULP**, is the raw material obtained by the chemical treatment of various coniferous and broad-leaved woods. In the earlier processes the disintegration of the wood was effected by treatment with acids, but in the more recent processes caustic soda and calcium sulphite are employed, the products being known respectively as soda cellulose and sulphite cellulose.

Since the durability of wood-pulp paper is greatly impaired by the presence of the substances known collectively as "lignin", the chief purpose of the processes employed is to remove this lignin from the woody fibers as completely as possible, thus obtaining the skeleton of nearly pure cellulose known as "wood cellulose." The treatment also aids in separating the fibers from one another without breaking or weakening them to any great extent. In carrying out the process, care must be taken to secure adequate mechanical division, to use solutions of sufficient concentration, and to treat at a high temperature and under pressure.[1] Wood boiled with caustic soda under suitable pressure is freed from the lignified material incrusting the walls of the fibers as well as the parenchyma elements of the medullary rays, etc., and is converted into a white fibrous mass consisting of nearly pure cellulose in the form of wood fibers. By the sulphite treatment, which depends on the solubility of the lignin in sulphurous acid, a material is obtained not unlike cotton in appearance.

Microscopic examination suffices for the identification of wood cellulose. The tracheids of coniferous woods (Fig. 91) are detached, colorless, very transparent, and laterally distended. Bordered pits are very indistinct and appear in most of the fibers merely as rounded somewhat jagged holes. Distinct lattice-like striations (*a*, *b*, and *) are often found on the walls. The ends are broadly rounded and swollen; some of the larger pieces (*b*) resemble cotton, but are readily distinguished by v. HÖHNEL's test.

The libriform fibers from birch and poplar wood resemble the vessels of coniferous woods and are of little service in diagnosis. Of greater value are the vessels with numerous pits, which are usually so well preserved as to establish the presence of a broad-leaved wood. The fibers of wood cellulose from birch have porous, partly thick and partly thin walls. The walls of the vessels are pierced by simple slit-like pores, while those of the poplar are bordered and, according to HERZBERG, have tail-like ends on both sides which often reach a considerable length.

---

[1] In the UNGER process 6 atmospheres are employed, in other processes 10–14 atmospheres.

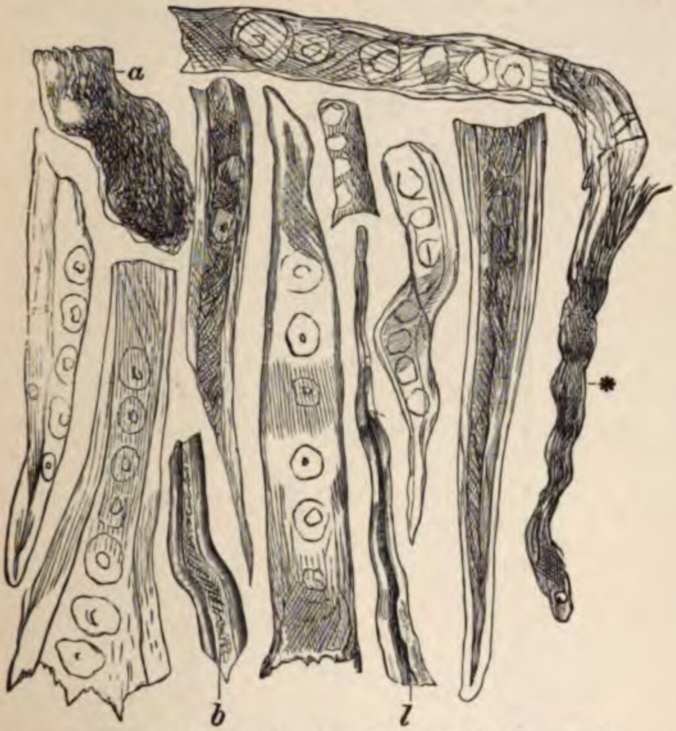


FIG. 91. Wood Cellulose from Pine. (T. F. HANAUSEK.)

a broad swollen end of tracheid; *b* fragment resembling cotton fiber. Some of the fibers show distinct lattice-like striations.

8. **SUGAR-CANE PAPER** (Fig. 92) is characterized by the abundance of very large finely porous parenchyma cells (*p*) and the exceedingly variable stone cells (*sc*). The sclerenchyma fibers are of three kinds, between which, however, are intermediate forms: (1) strongly thickened fibers with pronounced pores (*F*); (2) fibers about the same breadth as the last, but shorter and with much thinner walls (*f'*); and (3) very narrow forms (10–14μ) with tapering points (*f*), resembling flax fibers. The ends of the other forms are blunt or blunt-pointed and are mostly strongly thickened. All the fibers are strongly sclerenchymatized. Vessels with numerous pits or reticulated thickenings also occur in abundance in the paper.

9. **JAPANESE AND CHINESE PAPERS** are extraordinarily firm and tough, and at the same time very fine and soft. Under the microscope the fibers are very striking, as they are mostly uninjured and may be isolated entire. Mutilated or distorted fibers are rare. This perfect condition of the fiber is due partly to the nature of raw material and partly to the process of manufacture.[1]

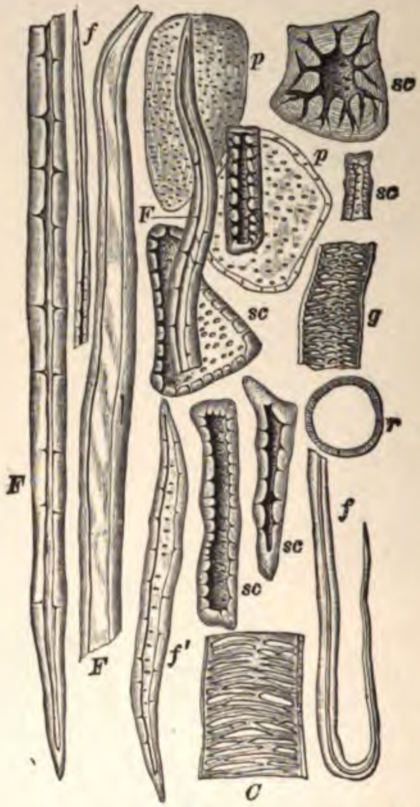


FIG. 92. Paper Pulp from Sugar Cane. (T. F. HANAUSEK.)
F large, *f* narrow, and *f'* short sclerenchyma fibers; *p* parenchyma cells; *sc* stone cells of various forms; *C* and *g* parts of vessels; *r* ring from annular vessel.

Chinese paper is made chiefly from bamboo or paper mulberry fibers, together with hemp, wheat straw, and rice straw. Rice paper is prepared from tissue elements in their natural condition obtained from the pith of *Aralia papyrifera* Hook.[2]

---

[1] See M. KRAFT: Lueger's Lexikon d. ges. Technik, **6**, 669.
[2] MOELLER: Bot. Ztg. 1879, **45**, 721.

Japanese paper is also manufactured from paper mulberry fibers and in addition from the bast fibers of **Mitsumata** (or more correctly mitzu mata), which, according to FRANCHET and SAVATIER, is *Edgeworthia papyrifera* Miqu. (order *Thymelæaceæ*). Mitsumata fibers[1] (Fig. 93) are of highly characteristic structure and are easily recognized in paper. They are very irregular, varying in width from 4 to 18μ. The ends are mostly rounded, or broadened, less often pointed, and are often forked, or branched; the lumen is often interrupted, the thickness of the walls varying greatly. The fibers are not lignified and yield the finest Japanese papers. Paper made from paper mulberry fibers contains not only bast fibers (p. 92) but also wood elements and parenchyma. The cells of the latter are very large, round, with numerous pits,

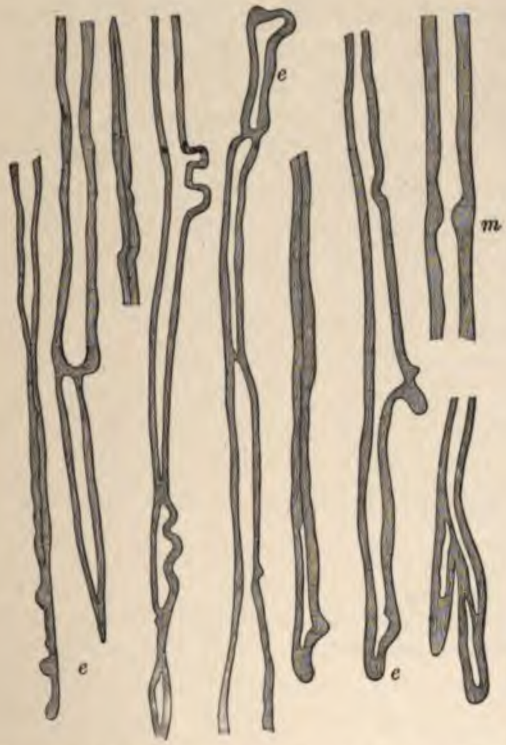


FIG. 93. Mitsumata Fiber from Japanese Paper. × 350. (T. F HANAUSEK.)
e end piece; *m* middle piece.

---

[1] See WIESNER: Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903, **2**, 447

each containing a short prismatic or rhombohedron-like crystal of calcium oxalate.

Gampi fiber is also used in Japanese paper. It is obtained from *Wikstrœmia sp.*, and is very similar to paper mulberry fiber.

10. **MISCELLANEOUS PAPERS.** In addition to the raw materials named numerous others are converted into paper pulp. Wrapping-paper, pasteboard, and other cheap kinds of paper often contain a variety of materials some of which are difficult to identify. Among the materials used are stems of rushes and coarse grasses, hop fibers, mosses, hay, ferns, and, recently, peat fibers. Even horse manure has been made into paper. Wool and animal hairs are seldom used, and then only in coarse paper. Silk, however, yields a high grade of paper remarkable for its toughness. Certain fibers exotic to Europe, such as pita hemp, sisal hemp, adansonia, Manila hemp, daphne fiber (Nepal paper is made from *Daphne cannabina*), bamboo sprouts, fibers of the paper mulberry, are also used in large quantities in paper manufacture.

Genuine **Papyrus**, the writing material of the ancient Egyptians, was prepared from the inner bundle-bearing pith-like portion of the stem of *Cyperus Papyrus* L.[1] So-called "tree-bast paper" (charta corticea), consisting of the separated inner layers of the bark of the birch, beech, linden, or other broad-leaved trees, was also used by the ancients for writing.[2] Much of the paper known under that name was, however, papyrus.

---

[1] WIESNER: Technische Mikroskopie, 1867, 237.

[2] WIESNER: Studien über angebliche Baumbastpapiere. Sitzb. k. k. Akad. Wiss. Wien, Phil. Hist. Cl. 1892, **126**, 8 Abhandlung.

CHAPTER III.

ANIMAL FIBERS. MINERAL FIBERS. TEXTILES

I. ANIMAL HAIRS (WOOL, ETC.).

AN animal hair consists of the **Root** situated in a depression of the skin (the hair follicle) and the **Shaft**, or hair proper. In a typical hair three sharply defined tissues are present: the **Epidermis**, or cuticular layer, the **Cortex**, or fiber layer, and the **Medulla**, or pith. Hairs are distinguished according to their length, stiffness, distribution on the skin, etc., as **Bristles**, **Bristle Hairs**, **Beard Hairs**, and **Wool**. The long stiff elastic hairs of the hog are typical bristles. Bristle hairs, that is short straight stiff hairs with a medulla, occur either in isolated groups (e.g., eyelashes, vibrissæ of the carnivora) or they form a somewhat stiff coat covering nearly the whole body (e.g., hair of the horse). Beard hairs are the long, straight or slightly wavy, regularly distributed hairs (almost always with a medulla) which give the pelts of various animals their value. Human hair, at least of the straight-haired races, and the hairs from the manes and tails of horses also belong in this class.

Wool, the most valuable of all hairs, is soft and flexible, either crinkled or straight. The wool of many animals has no medulla. Wool hairs are not evenly distributed like other hairs, but are arranged in tufts. The under coat of many hairy mammals is composed of this form.

The distinctions between the classes named are not sharp, all possible intermediate forms being of frequent occurrence. Although it requires but a glance in the microscope to show that a hair is of animal origin, it is a difficult matter to determine the animal from which it was derived. This is partly because of the similarity of hairs of certain animals and partly because of the variation of those from one and the same animal.[1] These points will be better understood after considering the microscopic characters of the different kinds of wool as detailed in the following sections.

---

[1] See also WOLLE: v. Höhnel's Mikroskopie der technisch verwendeten Faserstoffe Wien, 2. Aufl. 1905, 148 and 154.

The action of certain chemical reagents on animal hairs is highly characteristic. Nitric acid and boiling picric acid color them yellow; boiling chromic acid solution, also potash lye, dissolves them; boiling hydrochloric acid does not have any appreciable effect. Millon's reagent, on boiling, colors the fibers red. Wool has a disagreeable odor on burning, whereas the vegetable fibers give off no characteristic fumes.

MOLISCH'S REACTION[1] furnishes a sharp distinction of animal from vegetable hairs. The process is as follows: About 0.01 g. of the fiber is boiled for some time with water, thoroughly washed, and placed in a test-tube with 1 cc. of water, 2 drops of 15–20 per cent alcoholic solution of α-naphthol and sufficient concentrated sulphuric acid to double the bulk. If a vegetable fiber is present, the whole fluid on shaking becomes deep violet and the fiber dissolves. If, however, the fiber is of animal origin the solution becomes more or less yellow or red brown. If thymol is used instead of α-naphthol a cinnabar-red instead of violet color is obtained with vegetable fibers. Since the vegetable cell wall consists in large part of cellulose, and this, treated with water and sulphuric acid, is converted into sugar, the reaction is really between α-naphthol and sugar.

SHEEP'S WOOL.[2]

The larger part of the wool of commerce is derived from the domestic sheep, or true wool sheep. Other wool-bearing animals such as the Hungarian sheep, the Zigaja sheep, the Moorland sheep, etc., yield a fleece consisting of an inferior mixture of wool and beard hairs. The domestic sheep, commonly raised on the Continent and in Australia, are fine- or short-wooled breeds derived from the Spanish (originally Moorish) Merino sheep, of which there are two chief races: (1) the short-legged Negretti sheep, later known as Infantados, with pronounced neck folds and a dewlap, and (2) the tall, long-legged Escurial sheep. The

---

[1] Dingler's Polyt. Jour. 1886, **261**, 135.

[2] F. H. BOWMAN: On Some Variations in the Structure of Wool and other Allied Fibres. Proc. Roy. Soc. Edin. 1885–1886, **13**, No. 122, 657–672. T. F. HANAUSEK: Realenzyklopädie d. ges. Pharm., 2. Aufl., **12**, 691, and Materialenkunde des Thierreiches, **3**, 85. HANNAN: Textile Fibres of Commerce. London, 1902, 188. V. HÖHNEL: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 94. MATTHEWS: Textile Fibres. New York, 3d Ed. 1913, 14.

Saxon Electoral breed is a derivative of the latter race, while the Austrian Imperial and the French Rambouillet breeds are representatives of the former. The fleece of the fine-wool breeds consists entirely of true wool, while that of the English long-wool or luster-wool breeds, including the Lincolns, Leicesters, and Cotswold, consists chiefly of beard hairs, which, because of their fineness, are especially adapted for carding.

MICROSCOPIC STRUCTURE.

Animal hairs are mounted in water for microscopic examination. If, as is true of unwashed wool, the secretions of the skin known as "wool fat" and "wool sweat" remain adhering to the fiber, the fatty matter must be removed by ether or chloroform before mounting, otherwise the hair will repel the water. Wool hairs are 13–40μ broad, rather uniformly cylindrical, tapering only near the blunt-pointed "natural" ends. These tapering ends are always found on the wool of unshorn lambs and sheep and for this reason are designated "lamb ends". The appearance of the fiber changes with the focusing. If we focus on the surface at the highest part, we notice delicate, irregularly arranged transverse lines which here and there run together (Fig. 94, *a*). If, by a slight turn of the fine adjustment, we focus somewhat deeper, we observe that these lines extend to the border of the fiber and that delicate longitudinal striations appear beneath them, forming the inner zone, through which by deeper focusing we note cross-lines on the other side of the fiber. In this way we learn that the hair consists of two layers: the epidermis and the cortex or fiber layer. The **Cortex** consists of a cylinder, or (at the end) a cone, made up of short, very narrow, closely united fiber cells, to which are due the long logitudinal striations. When visible, the lumens of these minute fibers appear as dark striations. The cross-lines on the surface are the free ends of the **Epidermal Cells** or **Cuticular Scales**, which, like the scales of a fish, cover the inner cylinder of fiber cells. Rarely one of these scales extends completely around the shaft; usually, however, two form the circuit. The basal part of each is shoved under the scale below, while the upper edge, which is diagonal, irregularly wavy, or occasionally pointed or toothed, is free and stands out more or less from the fiber layer, so that in contour the hair appears to be upwardly barbed. These scales, according to NATHUSIUS, can be isolated by treatment with concentrated ammonia water, which has the advantage over sulphuric acid and some other reagents in that it does not cause them to roll up. Chromic acid or cuprammonia accomplishes the same result.

The Number of Scales on a given length of hair appears to be constant within narrow limits for each kind of hair. It should be remembered, however, that considerable variations may be observed on one and the same hair, the number often diminishing toward the apex; still, as a rule, the distribution over the surface appears to be quite uniform, and in the case of the wool of certain animals, particularly the Merino sheep and Angora goat, the results of counting tests[1] are of considerable value in identification.[2]

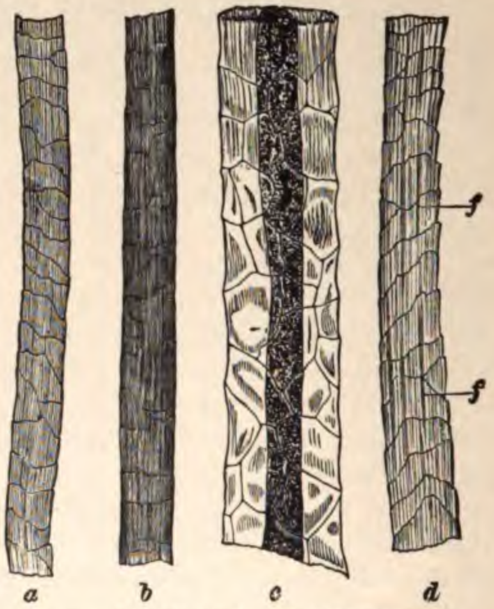


FIG. 94. Sheep's Wool. (T. F. HANAUSEK.)

a finest imperial wool (Merino) from a two-year-old ewe; wool hair over-bowed, 21μ broad; with eight epidermal scales in 100μ.—*b* horny luster hair from lamb's wool with epidermal scales very indistinct.—*c* and *d* Hungarian, straight, coarse wool: *c* beard hair; *d* wool hair with *f* cleft.

The following are the results of actual countings of the number of scales seen in 100μ lengths from the middle of the hairs. In each series 30 countings were made (of wool hairs only), the results given being the averages of these.

---

[1] T. F. HANAUSEK: Einige Bemerkungen zur Charakteristik des thierischen Haares. Jahresb. Wien. Hand. Akad. 1888, **16**, 107–110.

[2] Of course this one characteristic is not sufficient to positively identify a particular hair. A definite conclusion should not be reached until all the characters are considered.

NUMBER OF SCALES IN 100μ LENGTHS OF WOOL.

Series.	Ordinary Uncleaned Wool.	Merino Wool.	Angora Wool.
I.	10.9	11.1	5.4
II.	10.5	11.5	5.4
III.	10.8	11.5	5.3
IV.	10.0	11.5	5.38
V.	9.8	11.4	5.2
VI.	10.7	11.0	5.3
VII.	10.8	11.1	5.2
VIII.	10.5	12.0	5.3
Average	10.5	11.4	5.285

From these figures it appears that the scales on Angora wool are the most uniformly distributed.

A comparison of the average of all results obtained with various kinds of wool follows.

Kind of Wool.	Number of Scales in 100μ Lengths.
Sheep's wool, ordinary	10.5
prime, soaked	9.7
Merino, needle staple	11.4
superelecta	9.98
Saxon, prime carding	12.1
Angora wool	5.285
White alpaca	8.98
Brown alpaca	15.0
Vicuña	10.0
Camel's hair	8.99

Fineness.—Sheep's wool has only two tissues, the fiber layer and the epidermis. The breadth (thickness) of the hairs, the true measure of the fineness, is exceedingly variable. The following grading according to diameters has been used:

Grade.	Diameter of Hairs.
Superelecta	15–17μ
Electa	17–20
Prime	20–23
Second quality	23–27
Third quality	27–33
Fourth quality	33–40

Since the fineness of the wool bears a definite relation to the extent to which it is crinkled, attempts have been made to grade the product according to the number of bends in 1 cm., as follows: Superelecta, over 11; electa, 9–10; prime, 7–9; second quality, 6–7; third quality, 5–6; fourth quality, 4–5. The different kinds of crinkling, known as normal bent, close bent, high bent, flat bent, and long bent, also appear to be due to differences in the fineness, although little is known on this point. Fig. 94, *a*, shows an over-bent hair, Fig. 94, *d*, and Fig. 95, *d*, normal bent hairs. In spite of their similarity certain fine distinctions are noticeable; for example, as appears in Fig. 95, *d*, the edges of the scales are quite regularly parallel.

Kemps.—Occasional wool hairs differ quite markedly from the type in that the fiber layer is an almost homogeneous cylinder, and the epidermal scales appear to be absent or their contour is only here and there distinct. These hairs are known as kemps, luster hairs, or dog hairs. They are unfit for dyeing and, although always found in normal fleece, their presence in considerable amount renders the wool of inferior value. The term dog hairs is also applied to the occasional beard hairs found in the wool of fine-haired sheep.

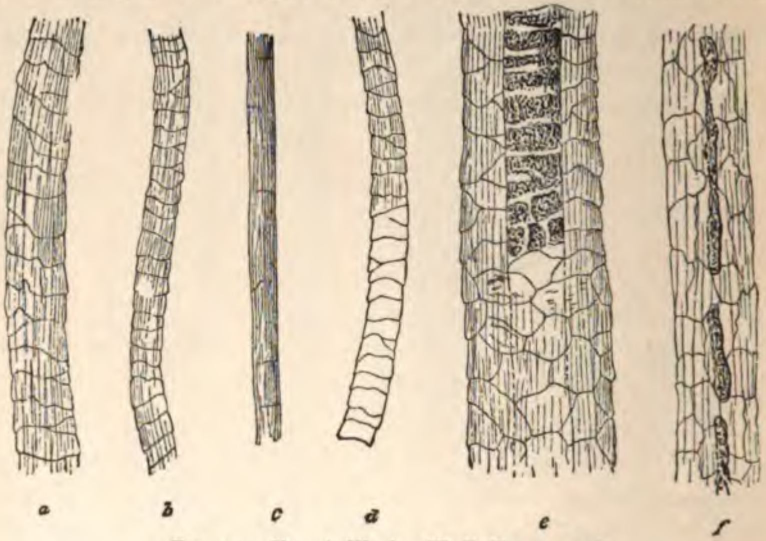


FIG. 95. Sheep's Wool. (T. F. HANAUSEK.)

a–c Hungarian Merino, second quality, washed: *a* broad (40μ) wool hair (10 scales in 100μ); *b* narrow (18μ) wool hair (11 scales in 100μ); *c* narrow, horny hair.—*d* Electoral-Negretti, first quality, unwashed, normal-bowed (17μ broad, 10 scales in 100μ).—*e* and *f* Hungarian horned sheep: *e* broad (90μ) beard hair with medulla 40μ broad; *f* beard hair (62μ broad) with interrupted medulla.

Burs.—In the microscopic examination of wool due allowance must be made for the condition of the product, especially whether or not it has been washed and thus freed from wool sweat, dust, and other adhering impurities. The wool from South America and some other regions contains a considerable amount of "burs"—that is, fruits with hooked prickles—of various plants (chiefly legumes, such as *Medicago*), which are not easily removed, and consequently lessen considerably the value of the product.

In the spinning of such wool, vegetable fibers from the fruits become incorporated in the thread, which must be recognized by the microscopist as accidental admixtures.

Coloring.—It should be observed whether the hairs are colored or not, and, in the former case, whether the color is the natural gray, brown, or black of dark wool, or whether it is due to a dyestuff. The natural coloring matter occurs in the medulla and fiber layer in the form of fine granules. Again, due regard should be given to the changes undergone in the process of manufacture.

Abnormal Hairs.—The hairs of yarn and, in a greater degree, of fabrics are often deprived of the epidermis, bruised and therefore contracted, torn, fringed at the ends, also here and there crushed and resolved into the individual fibers. These phenomena will be considered later under the heads of Examination of Fabrics (p. 157) and Shoddy (p. 141).

Occasionally wool contains hairs which are constricted in one place or less often in several places. If this occurs in many of the hairs it indicates that the animal suffered from disease, hunger, thirst, or lived under other abnormal conditions, as whatever affects the growth of the body as a whole also affects the growth of the hairs.

Beard Hairs, with few exceptions,[1] are made up of three tissues—the epidermis, the cortex, and the medulla. The latter, forming the core of the hair, consists of 1–4 rows of rounded or elongated "parenchyma" cells. The cell walls are for the most part very thin and indistinct, and the contents consist of finely granular masses, air,[2] and, in the case of colored hairs, of pigment granules. In most cases the medulla consists of a continuous axial cylinder of cells, but sometimes the continuity is interrupted, the isolated cells or groups of cells forming the so-called medullary islands. The medulla is absent in the points.

The hairs of different animals, such as the hare, the deer, and the cat, furnish excellent practice material for the beginner, as they illustrate the extraordinary variations in the structure of the medulla.[3]

---

[1] The Zigarra wool of southern Hungary has beard hairs without medulla.

[2] In cow hairs air also occurs between the cells.

[3] CHAS. C. CURTMAN: Haare und ihre Bedeutung in der gerichtlichen Medizin. (Treats on different forms of human hair and hair of the leading types of mammals.) Pharm. Rund. 1895, **13**, 252–260. C. HASSACK: Beiträge zur Kenntniss der Pelzwaaren. Ztschr. Nahr. Unters. Hyg. Warenk, 1893. MOELLER: Mikroskopische Beschreibung der Thierhaare. Arch. Kriminal-Anthropologie u. Kriminalistik, 1899, **2**, 177–210. W. WALDEYER: Atlas der menschlichen und thierischen Haare. Lahr, 1884.

The distinction of varieties of sheep's wool from goat's wool is explained on pp. 134 to 137.

The thickness of the medulla in most beard hairs is less than that of the fiber layer; in some cases, however, it is greater, reaching in extreme cases four fifths of the diameter of the whole fiber. As a rule the structure of the epidermis in hairs having a medulla is different from those without. The epidermal cells are usually much narrower than the hairs, and the outlines form an apparent network over the surface (Figs. 94, *c* and 95, *e*). They may also be concave, so that the contour of the hair shows a series of rounded depressions (Fig. 94, *c*).

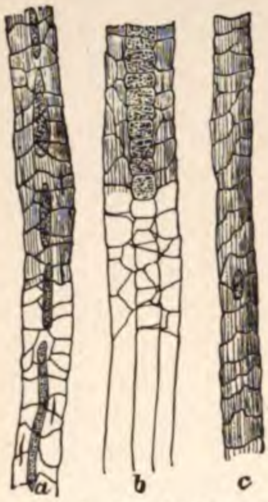


FIG. 96. Beard Hairs of Leicester Sheep's Wool. (T. F. HANAUSEK.)

a and *c* with interrupted medulla; *b* with continuous medulla. *c* 30μ broad with 8.6 epidermal scales in 100μ; *a* 50μ broad.

While common wool consists of both wool hairs and beard hairs, the wool of Leicester sheep consists almost entirely of beard hairs, the structure of which is as follows (Fig. 96). The hairs are 25–50μ or more broad, distinctly striated, with an interrupted medulla (*a*, *c*), or a continuous medullary cylinder (*b*). Toward the apex the medullary tissue is but sparingly developed. In narrow hairs 1–2 epidermal scales are found in each cross-section, but in broad hairs they are so numerous as to form very irregular reticulations over the surface. The free ends of the scales are irregular, frequently toothed, one of the teeth often being more conspicuous than the others. The number of epidermal cells in 100μ may be as low as 7, but usually is 8–9. Although Leicester wool can not be positively identified by microscopic examination, the characters noted, as well as the facts that it consists almost entirely of beard hairs and that these are never so thick as in common wool, are of value in diagnosis.

GOAT'S WOOL.

1. **ANGORA WOOL**, or **MOHAIR**, is obtained from the Angora goat, which breeds in the mountains of Angora and Koniah in Asia Minor. It varies greatly in fineness and quality, the finest being pure white, silky lustrous, with hairs several dm. long and 12–54μ, usually 30–44μ, thick, while the inferior grades are mostly brown and with coarse, distinctly striated hairs having well-developed medulla. The wool hairs (Fig. 97, *a* and *c*, Fig. 98)

are without medulla, have a strongly developed fiber layer with broad clefts (Fig. 98, *sp*) and half-cylindrical or cylindrical epidermal cells, which are characterized by their unusual height (only 5–6 to 100μ; see Sheep's Wool, p. 126) and finely toothed edge (Fig. 98). At the present time a so-called Angora wool is on the market which is probably obtained from the Persian goat, and is characterized by the presence of beard hairs up to 150μ broad with a medulla. The skins are much prized for rugs. Often the skins of the long-haired Southdown sheep are sold as Angora rugs.

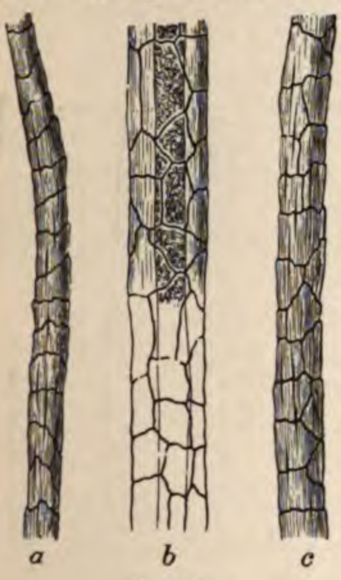


FIG. 97.

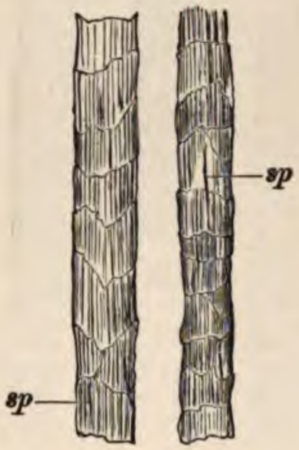


FIG. 98.

FIG. 97. Angora Wool. ×200. (T. F. HANAUSEK.)

a finest Angora wool hair; 12.5μ broad, 5–6 epidermal scales in 100μ. *b* narrow (40μ) beard hair with medulla 15μ broad. *c* broad (25μ) wool hair with conspicuous clefts.

FIG. 98. Angora Wool. ×400. (T. F. HANAUSEK.)

A variety with broad wool hairs; epidermal scales finely toothed. *sp* clefts.

Angora wool is used, with ramie, for fine-carded fabrics, in half-silk goods and, colored, in artificial hair.

2. **CASHMERE,** or **THIBET WOOL**, the long silky wool of the cashmere goat, is white, yellow, or brown, and consists of very fine cylindrical wool hairs, 7–8 cm. long and 13–20μ thick, the epidermal cells of which are finely toothed (Fig. 99, *a*, *b*), and of such a height that 6–7 occur in each 100μ. The fiber layer is strongly developed and shows fiber clefts. The occasional beard hairs contain a continuous medullary cylinder.

3. **COMMON GOAT'S WOOL.**—The coat of the ordinary goat (Fig. 100) is largely made up of beard hairs, most of which still have the roots attached. The structure, which differs in different parts of the same hair, is described by v. HÖHNEL[1] as follows: "The average hairs are about 80–90μ thick at the base and the root is about ⅓ mm. long. In the root the medulla is narrow, but increases very rapidly in diameter until, at a distance of a few mm. from the base, where the diameter of the hair is 80–90μ, it reaches 50μ. Obviously the fiber layer is relatively thin. In cross-section the hair is round. The epidermis consists of broad scales about 15μ high, the ends of which are not thickened, but form a distinctly wavy (but not dentate) line of demarkation. For a considerable distance the fiber is not over 100μ, of which 80μ is medulla. The medullary cells are thick-walled, broader than high. Toward the middle the hair is again

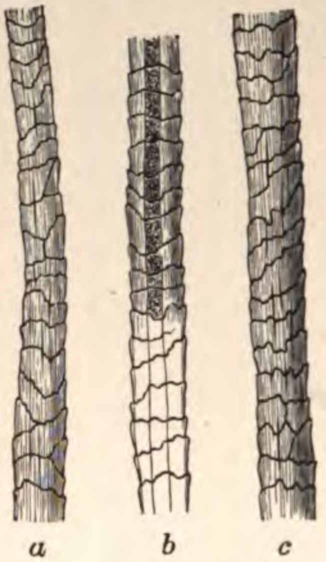


FIG. 99.

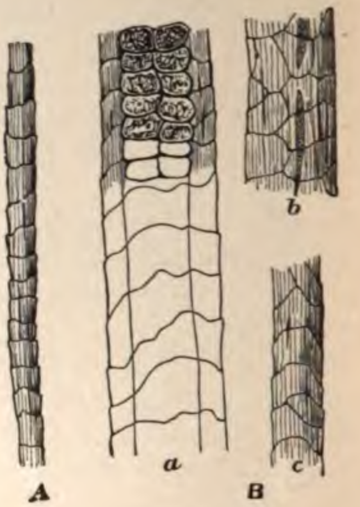


FIG. 100.

FIG. 99. Cashmere and Chinese Goat's Wool. (T. F. HANAUSEK.)

a and *b* cashmere wool: *a* wool hair with 6–7 epidermal scales in 100μ; *b* beard hair, 30μ broad.—*c* Chinese goat's wool: wool hair 30μ broad, with 7 epidermal scales in 100μ.

FIG. 100. Common Goat's Wool. (T. F. HANAUSEK.)

A wool hair from so-called goat down (12μ broad, 12 scales in 100μ).—*B* hair of buck: *a* with medullary cells in several rows (60μ broad, 7 scales in 100μ); *b* with interrupted medulla (45μ broad); *c* without medulla (25μ broad, with 6 scales in 100μ). In *a* only part of the fibers and medullary cell are shown.

---

[1] Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 177.

narrower, but near the apex it reaches its greatest diameter of about 130μ, the fiber layer being here relatively narrowest (6μ) and the medulla broadest (6–10 rows of cells). Here the hair, owing partly to the lime or other ash constituent, is very brittle."

Other authors note the presence of very narrow air clefts between the medullary cells, especially in those parts where only one row of these cells is present.

v. Höhnel further states that toward the apex the medulla narrows rapidly to a single row of long cells, then to detached groups, and finally, when the hair is reduced to a diameter of 40μ, it disappears entirely. In the elongated tip the epidermal scales are dentate and correspondingly higher.

The beard hairs are somewhat different in structure from the wool hairs.

In Fig. 99, *c*, is shown a wool hair of the Chinese goat. All goat wools have 5–7 scales in 100μ lengths from the center of the hair.

COW HAIR.

The coat of the cow is composed partly of wool hairs without medulla and partly of coarse and fine beard hairs. In the coarse beard hairs (Fig. 101, *c*) the medulla is very broad, single-rowed, with narrow distinctly outlined cells, between which here and there are intercellular fissures filled with air. The fiber layer is thin and finely striate, and the closely arranged epidermal scales are irregularly and finely dentate. The fine beard hairs have an interrupted medulla of thin-walled narrow cells (Fig. 101, *a*), and cylindrical finely dentate epidermal scales so closely arranged that there are about 12 in 100μ. Here and there occur scales with an elongated tooth. The apex is without medulla and mostly without epidermal scales; at least these are not distinct. The arrangement of the medullary tissue is as follows: The medulla begins immediately over the narrow constriction at the base as a continuous cylinder, and breaks up further on into detached groups of cells which disappear entirely in the center of the hair; beyond the center the groups appear again, then unite to form a narrow one-rowed continuous cylinder, and finally disappear in the apex.

The diameter of the coarse hairs is 120–130μ, of the fine hairs 65–80μ. Of a diameter amounting to 100–110μ, 75–80μ is medulla.

Cow hairs are easily distinguished from goat hairs by the number of scales, the single-rowed medullary cylinder, and the fissures between the medullary cells.

CALF HAIRS have the same structure as cow hairs.

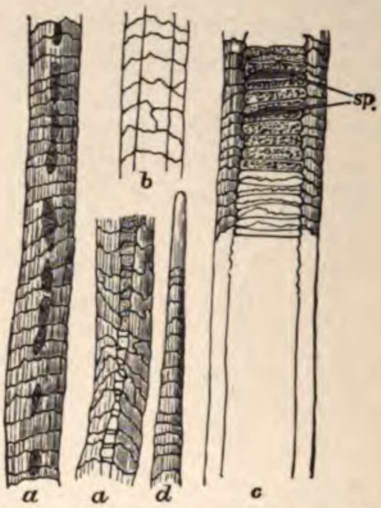


FIG. 101. Cow Hairs. (T. F. HANAUSEK.)

All the hairs shown are beard hairs. *a* middle part, with interrupted medulla or narrow medullary cylinder; *b* and *c* middle part with broad medulla, in *c* the narrow medullary cells are distinct and between them occur clefts (*sp*) filled with air; *d* end part with apex free from scales. *a* is 40μ broad with 12 scales in 100μ; *c* is 65μ broad.

DISTINCTION BETWEEN SHEEP'S WOOL, GOAT'S WOOL, AND COW HAIR.

Certain kinds of sheep's wool resemble very closely goat's wool. Coarse native wool consists sometimes of long rigid white and black hairs, also of white hairs with dark points, which externally cannot be distinguished from goat hairs. Even under the microscope these show a similarity which at first sight is very striking. Goat hairs in their middle part are characterized by the broad, but short, parallel medullary cells. Air (together with the dried granular contents) is commonly present in the medullary cells of white hairs, giving the medulla the appearance of a broad, black band which is here and there lighter, and shows the cell boundaries in the form of more or less parallel transverse lines. These boundary lines are especially distinct at the periphery of the medulla adjoining the fiber cylinder. In a sample of sheep's wool submitted for examination numerous beard hairs were present, which are shown in Fig. 102 *A*, *G*.

The similarity to goat hairs is striking. The medullary cells appear to be broad, with more or less parallel boundary lines—an appearance which we will see later is deceptive. The presence of much air in the cells makes the medulla appear almost black, thus increasing the resemblance to goat hairs. If we compare the two hairs shown in Fig. 102, it is at once apparent that the accurate distinction of these kinds of wool is extraordinarily difficult. The distinction in the height of the individual (apparent) marrow cells, which in sheep's wool (*A*) are somewhat higher than in goat's wool (*B*), is not decisive, since this may be due to the breed, age, or climatic conditions.

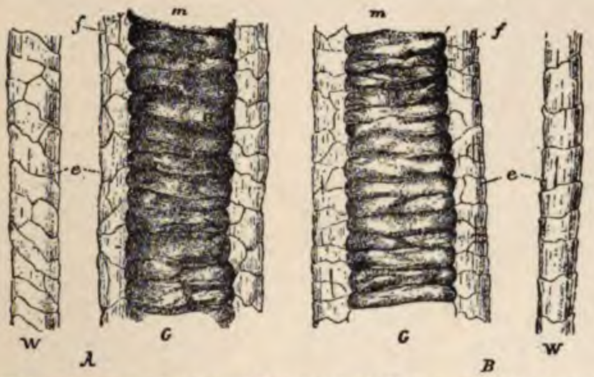


FIG. 102. Hairs of Sheep's Wool and Goat's Wool, Untreated. (T. F. HANAUSEK.)

A sheep's wool: *G* beard hair with apparently transversely elongated medullary cells which, being partially filled with air, are black; *W* wool hair, 32μ broad, with 8 epidermal scales in 100μ—*B* goat's wool: *G* beard hair with transversely elongated medullary cells filled with air and consequently black; *W* wool hair, 20μ broad, with 6.5 epidermal scales in 100μ; *m* medulla; *f* fiber layer; *e* epidermis.—The boundary lines of the epidermal scales over the medulla are not shown so as not to obscure the latter.

Since soaking in alcohol to drive out the air and warming in water did not make the structure distinct, I concluded that more information could be gained by swelling the hairs and resolving them into their histological elements, particularly those of the medulla. For this purpose potash was employed and with the result that much sharper and surer distinctions were obtained and all doubts were removed. If a potash mount is warmed until the first bubble appears, the hair swells greatly, the fiber layer dissolves, forming colorless streaks, and the medullary cells stand out very sharply and distinctly. In the wool in question the latter appear as large round cells with thickenings like those of vegetable collenchyma (Fig. 103, *A*), while in goat's wool they remain elongated and the original parallel arrangement is not altered (Fig. 103, *B*). This extraordinary difference in the appearance permits the distinction of sheep's wool and goat wool at a single glance. At my request Prof. v. HÖHNEL also has given this test a trial, and he has pronounced it "a good aid to better distinction." He also called my attention to the fact that the coarser Leicester wools have transversely elongated medullary cells at the lower ends of the hairs, and therefore strongly resemble goat hairs. English Leicester wools, as is well known, consist only of beard hairs as distinguished from Merino wool which consists only of wool hairs, and from common native wool, which consists of both beard and wool hairs. The finest grades of this wool are spun into English worsted yarn, a product noted for its excellence. In one sample of Leicester wool in my collection with beard hairs, 62 μ and over broad, there are hairs with transversely elongated medullary cells (Fig. 104, *A*) resembling closely goat hairs. These differ from the beard hairs of the sheep's wool described above in that the medullary cells are not so high and therefore approach more nearly goat hairs. Here again, however, warming with potash brings out the distinction. Fig. 104, *B*, shows the rounded medullary cells characteristic of sheep's wool, which differ from those of common native wool in that they have the same parallel arrangement as in the original wool. The cut shows only the outer layer of cells, although the inner cells are evident in the mount through these outer cells.

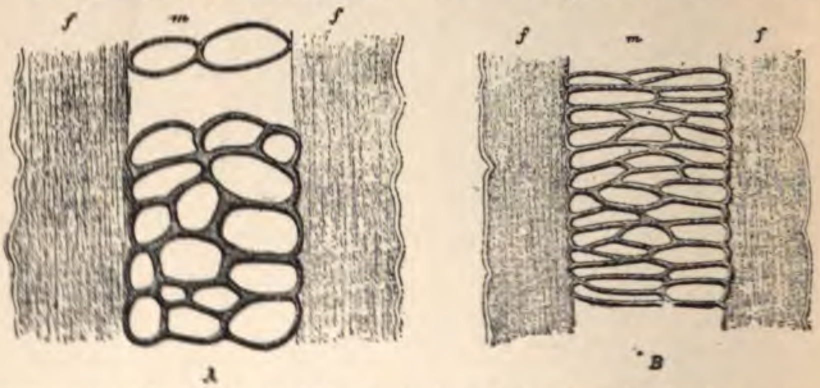


FIG. 103. Beard Hairs of Sheep's Wool and Goat's Wool after Warming in Potash. (T. F. HANAUSEK.)

A from sheep's wool; *B* from goat's wool. The medullary cells (*m*) are collenchymatously swollen and show distinct lumens; the granular contents are not shown. *f* disintegrated fiber cells.

Deportment of Cow Hair.—It is interesting to note the behavior of cow hair with potash, since in this, as in goat hair, the medullary cells are transversely elongated and arranged parallel to one another. An important distinction from goat hair is the presence of transverse air spaces, which with the growth of the hair increase in size, causing a shrinking or absorption of the medullary tissue. Naturally these air spaces may also be formed by the outer tissues increasing in length faster than the medullary cells. Fig. 104, *C*, shows two pieces of hairs after treatment with potash. Above we see a piece with thin-walled transversely elongated medullary cells united into small interrupted groups; in swollen hairs the air spaces are considerably enlarged. Below is shown the characteristic deportment often noticeable in thick, light-colored hairs; a continuous air space penetrates the medullary cylinder, while the medullary cells are attached by their broad bases to the inner side of the fiber cylinder, with their points directed inward, forming in parts small pyramids.

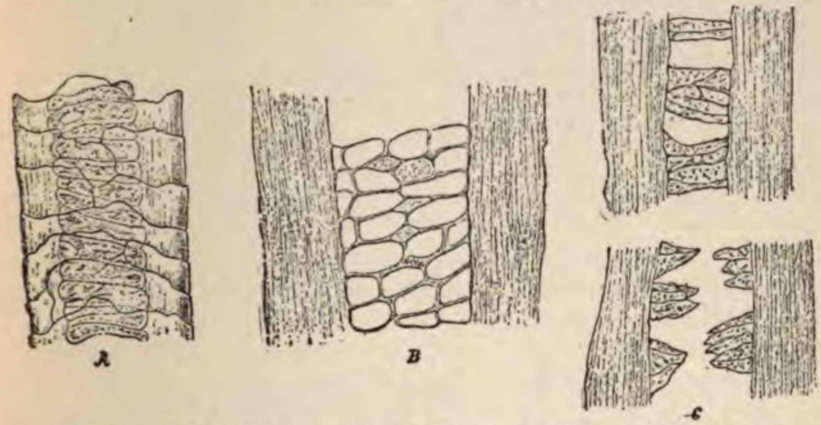


FIG. 104. Hairs of Leicester Sheep's Wool and Cow Hairs. (T. F. HANAUSEK.)

A part of hair of Leicester wool in water; *B* same after warming in potash; *C* pieces of cow hair after warming in potash.

In my opinion a much more accurate knowledge of the structure of many hairs, particularly those of a complicated nature, may be obtained by the aid of potash. This reagent serves merely to render the histological elements more distinct until finally the hair itself goes into solution. A study of cross-sections is also recommended.

CAMEL'S HAIR.

The hair of the camel consists of narrow wool hairs without medulla and very broad beard hairs. The latter (Fig. 105, *G*; Fig. 106, *g* and *g'*) are dark brown to black except at the apex, where they are lighter, 6–9 cm. or more long, 40–110μ broad, with a broad, or less often narrow,

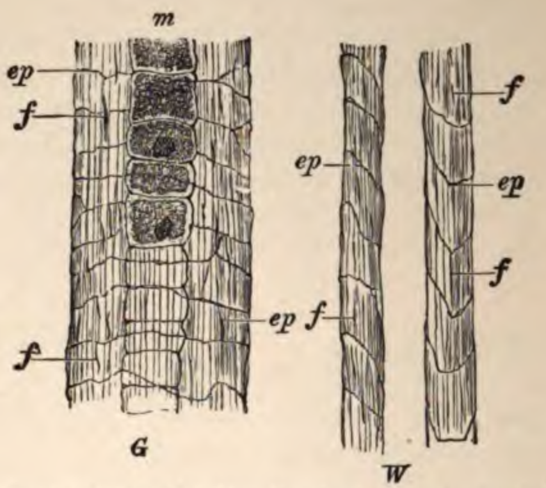


FIG. 105. Genuine Camel's Hair from *Camelus bactrianus*. (T. F. HANAUSEK.)

G beard hair; *W* wool hair. *ep* epidermal scales; *f* deposit of pigment; *m* medullary cells (only a few drawn with contents).

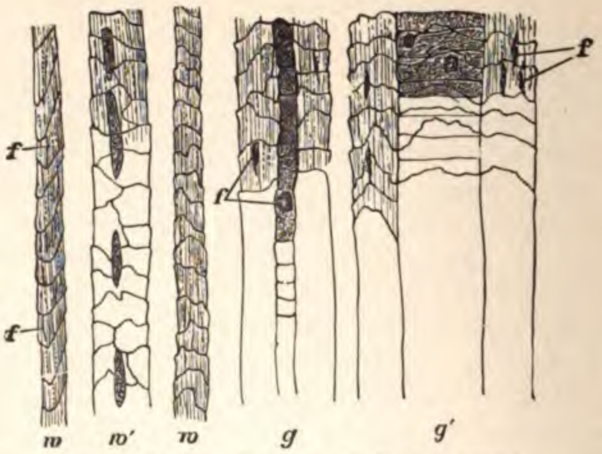


FIG. 106. Camel's Hairs. T. F. HANAUSEK.)

(A different sort from that shown in Fig. 105.)

w wool hairs; *g* beard hair with narrow medulla; *g'* beard hair with broad medulla; *w'* intermediate form with interrupted medulla. *f* accumulations of pigment. *w* 20μ and 25μ broad with respectively 6.5 and 7.0 scales in 100μ; *w'* 40μ broad; *g* 60μ broad; *g'* 110μ broad. The first wool hair is shown inverted, with scales pointed downward; in *g* and *g'* only part of the epidermal scales, the fibers, and the medullary cells are shown; in *w'* the fibers are shown only in the upper part.

continuous medullary cylinder. The epidermal cells are thick at the edges, giving the hair in longitudinal view a faintly saw-toothed outline. The fiber layer is distinct and contains an accumulation of dark-brown material in short thick streaks distributed here and there among the fibers (*f*). As a rule the medullary cells are in a single row, are short but broad, have distinct cross-walls, and are filled with a granular coloring material which in many cells forms dark-brown to black rounded accumulations. The wool hairs are regularly curled, fine, soft, reddish or yellow brown, uniform in breadth (16–25μ), very finely and regularly striated, the striations in parts being of a darker color owing to the pressure of rows of colored granules (Fig. 105, *W*; Fig. 106, *w*, *f*). The epidermal scales are high, with diagonal, more or less sharply bent edges, but without teeth. There are 6.5–8.99 scales in 100μ.

Camel's hair is distinguished from cow hair by the thick-walled medullary cells and the streaks and balls of coloring material.

ALPACA, VICUÑA, LLAMA, HUANACO.

Four species of goat-like animals belonging to the camel family yield hair of industrial importance. Two of these, the alpaca goat (*Auchenia Paco*) and the llama (*A. Lama*) are domesticated, while the other two, the vicuña (*A. Vicunna*) and the huanaco (*A. Huanaco*) occur only wild.

Huanaco and vicuña wool are now seldom found on the European or American market. What is often known in commerce as vicuña is a mixture of sheep's wool and cotton. Llama wool is also seldom exported under that name, although it is probable that alpaca sometimes contains an admixture of this wool. Microscopic examination is of little or no value in distinguishing the hairs of these species from each other, partly because in none are there marked characteristics not found in the others, and partly, as noted by v. Höhnel, because the fleece from different parts of the same animal differs in each species as to color, fineness, and freedom from stiff hairs.

The commercial products contain both beard hairs and wool hairs.

MICROSCOPIC STRUCTURE.

Examination of an authentic sample of vicuña wool (Fig. 107) shows that the beard hairs are lighter in color than the wool hairs, some being colorless, and that they are 68–80μ broad with a continuous medullary cylinder. The wool hairs are 14–18μ broad, free from medulla, partly yellow, partly colorless, very smooth; they have very indistinct epidermal scales with entire or only slightly toothed edges and very delicate striations. The number of epidermal scales in 100μ is very variable and may reach 15 (see p. 126), but on the average is about 8. As is also true of llama wool, the scales are of unequal height. There is also an abundance of forms (f') intermediate between beard hairs and wool hairs. These are 34–40μ in diameter and have interrupted medulla.

The beard hairs of alpaca are 25–60μ in diameter and have an apparently continuous medulla without cell structure. In a yellow-brown sort v. Höhnel[1] found in the medulla coarse grains which appeared like fragments of crystals. The brown coloring matter is irregularly distributed and here and there forms coarse streaks.

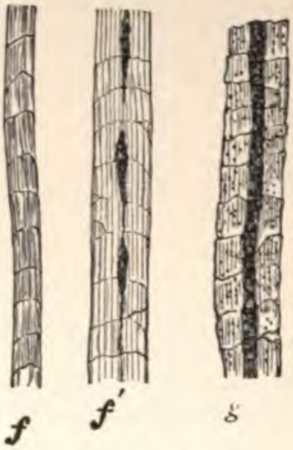


Fig. 107.

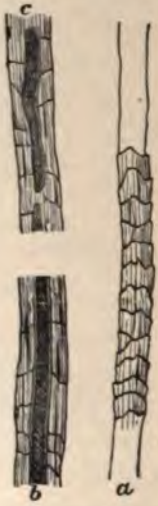


Fig. 108.

Fig. 107. Vicuña Wool. (T. F. Hanausek.)

f wool hair; *f′* hair intermediate between wool hair and beard hair, with interrupted medulla; *g* typical beard hair. The fine striations at the edge of the medulla are not shown.

Fig. 108. White Alpaca Wool. (T. F. Hanausek.)

a wool hair, 15μ broad with 9 scales in 100μ; *b* narrow beard hair, 25μ broad; *c* intermediate form with interrupted medulla and very indistinct epidermal cells 25μ broad. In *b* the medulla at the edge has fine striations resembling fine teeth.

In a sample of alpaca examined by the author the wool hairs (Fig. 108, *a*) were covered with epidermal scales the irregular edges of which were partly arched and partly 1–2-toothed. Distinct fiber clefts were noticed in the beard hairs (Fig. 108, *b*). The dense contents of the medulla were uniformly and finely granular without large flecks, but in the outer portion showed a peculiar structure previously noted by v. Höhnel.[1] This consists of numerous very short, narrow, transversely arranged, parallel lines which disappear in the granular contents of the medulla, but give the outer boundary of the medullary cylinder a very finely serrate appearance. These striations were observed in the detached medullary areas. The explanation of this appearance is found by comparison with the border of the medullary cylinder in other hairs. The parallel lines are evidently nothing more than the cross-walls of exceedingly narrow cells which are evident at the border, but further inward are obscured by the granular contents. From this it is also evident why the medulla in other hairs of this group appears to be non-cellular.

---

[1] Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 185.

In hairs with interrupted medulla (Fig. 108, *c*), which show certain characters intermediate between those of beard hairs and true wool, the epidermal scales are often very indistinct and appear in spots to be lacking or only incompletely developed.

SHODDY.

Renovated fibers recovered from woolen rags are extensively used in cheaper woolens. The product differs greatly in value and is variously designated according to the nature of the rags. **Shoddy** and **Thibet** are obtained from unfelted rags, **Extract Wool** or **Alpaca** from rags containing both woolen and vegetable fiber, **Mungo** from felted woolen rags.

In the manufacture of shoddy a certain amount of new wool is commonly added to give it strength; on the other hand, natural wool is extensively adulterated with shoddy and as a consequence suffers greatly in strength and durability. Thanks to the investigations of Cramer,[2] and especially v. Höhnel,[3] the detection of shoddy by microscopic examination is in most cases possible, although the task is one of the most difficult imposed on the technical microscopist and requires considerable experience and a careful comparison with standard materials.

In this investigation the following points noted by v. Höhnel should be considered:

---

[1] *Loc cit.* 186.

[2] Programm des Polytechnicums. Zurich, 1881, 8.

[3] *Loc. cit.* 168.

1. **Foreign Fibers.**—Only the most expensive fabrics are made from wool of uniform structure. Even in fine wool, beard hairs are found, although in very small numbers; therefore care should be taken not to consider a few hairs of different form as indicating the presence of shoddy. Even vegetable fibers occur in woolen fabrics without their being intentionally added. Wool from South America contains a considerable amount of *Medicago* burs, the histological elements of which find their way into the fabrics. On the other hand, the absence of vegetable fibers is no proof of the absence of shoddy, since in preparing the latter these are often removed by "carbonizing", i.e., treatment with dilute sulphuric acid and drying. If, however, multicolored cotton or cosmos fibers (p. 82) are detected the presence of shoddy may usually be positively affirmed.

2. **The Length of the Fibers** is not always a criterion. Generally the fibers are shorter in shoddy than in natural wool, but sometimes they are longer than those of the common sorts of wool. Then again the shearings from new woolen goods, the fibers of which although new are very short, are used as a filler. These may be detected by the two smooth, truncate, often somewhat flattened cut ends.

3. **The Diameter of the Fibers** is of uncertain value.

4. **Absence of Epidermal Scales** is no certain indication of shoddy, since these are torn off from many of the beard hairs of common wool.

5. **The Appearance of the Ends of the Fibers** is, as has long been known, one of the surest means of detecting shoddy. Since the fibers are obtained by shredding the rags in such a manner as to tear apart the yarn and the individual hairs of the yarn, most of the hairs have torn ends which, because of the liberation of the individual fiber cells of the cortex, present a fringed appearance (Fig. 109, *e*). Short pieces of hairs with fringed ends are highly characteristic of shoddy. Other indications of disintegration are the rents at the bends, the bruised spots with cortical fibers more or less separated (*q*), and the occasional torn ends (*b*). In parts where the cortical layer owing to bruises is separated into its elements the epidermis is also disorganized or entirely lacking.

It should be stated, however, that fringed ends and bruised spots also occur in natural wool, especially if it has been dyed, and their presence does not positively indicate shoddy any more than the presence in small numbers of a few "lamb ends" indicates lamb's wool. Great care should therefore be used in interpreting the results of observations. Only when many short pieces of hairs with fringed ends are observed, and further, when there is a striking lack of uniformity in the diameter of the hairs and in the appearance of the cuticle, is the microscopist justified in declaring that shoddy is present.

6. **Fibers of Many Colors** in shoddy are the surest means of identification. This test is infallible. Many woolen fabrics and the rags from such fabrics contain threads of various colors, the hairs of which, when made into shoddy, can be found under the microscope. If in addition the colored pieces of hairs are short and have fringed ends, the evidence is still more complete. While the presence of such colored hairs is positive evidence of shoddy, their absence is no proof that shoddy is not present, as that made from certain uncolored woolen fabrics contains no colored hairs. Furthermore, the colors are often concealed by subsequent dyeing, although in such cases the last dye may usually be removed by treatment with hydrochloric acid, after which the original colors reappear with more or less distinctness. Also on treatment with potash different colors appear as the fibers swell through the action of the alkali.

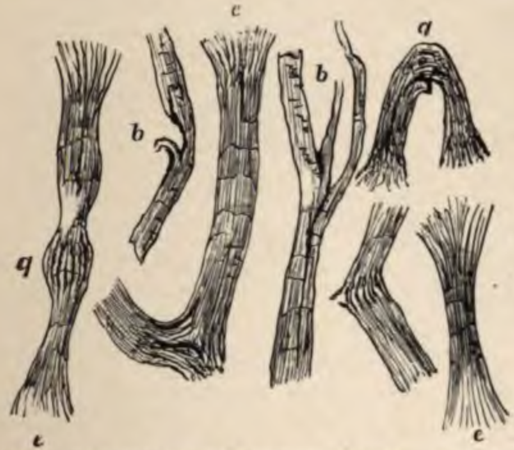


FIG. 109. Pieces of Sheep's Wool Hairs from Shoddy. (T. F. HANAUSEK.)
e fringed ends; *b* torn places; *q* bruises with striations.

From what has been stated it is evident that the detection of shoddy in yarn or fabrics is a very difficult and, under some conditions, an impossible undertaking. The microscopist who attempts it must first investigate numerous samples of colored and uncolored woolen fabrics made from natural wool. Especially useful are microscopic examinations of woolens with a rough nap due to fulling, teasing, shearing, and pressing, since in this nap mutilated hairs such as have been described may often be observed.

Among the practical examples given at the close of the chapter are some relating to the detection of shoddy in woolens.

II. SILK AND SILK SUBSTITUTES.

COMMON SILK.[1]

Under the general term "silk" are included the thread-shaped secretions of various animals which, owing to their strength and other desirable qualities, are used as textile fibers.

Silk, in the restricted sense, common or real silk, is the textile fiber from the cocoon spun by the larva of the mulberry silkworm (*Sericaria* [*Bombyx*] *mori*). It excels all other textile fibers in fineness, flexibility, firmness, and luster, and since the earliest times has been rated as the most valuable and beautiful of textile materials.

The full-grown larva secretes in the two tube-like silk glands a viscous fluid, the **Fibroin** or silk fiber, and in two other glands the **Sericin** or silk glue. The double silk fiber (**Bave**) ejected from the mouth in the form of two exceedingly fine threads (**Brins**), cemented together by the silk glue, is spun into the cocoon consisting of three distinct layers: (1) the **Floss**, a loose outer envelope made from the fibers first ejected, which serves to hold the cocoon in shape; (2) a **Middle Layer** of threads beautifully woven into an interlacing pattern; and (3) the **Parchment**, a smooth inner layer containing a larger percentage of glue than the other layers. Only the fibers of the middle layer can be removed by reeling, the outer and inner layers being waste products of secondary value.

In order to remove the outer fibers and dissolve off the outer portion of the silk glue from the good fibers preparatory to reeling, the cocoons are plunged in hot water, beaten with switches and brushes, after which the outer end of the middle fiber layer is picked up and the whole network is removed as a continuous filament by reeling. In the reeling process the filaments from 2–15 cocoons are united to form a thread which, in order to cause the sericin to cement together the filaments, is run through one or two rings of glass, ivory, or some other hard material and, after passing through a drying-room, is finally wound on a reel. Another method of effecting a thorough union of the filaments during reeling is to cause two threads to rub against each other by twisting, after which they are separated by passing through separate eyes.

---

[1] HANNAN: Textile Fibres of Commerce. London, 1902, 165. v. HÖHNEL: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 199. MATTHEWS: Textile Fibres. New York, 3d Ed., 1913, 105. H. SILBERMANN: Die Seide, ihre Geschichte, Gewinnung und Verarbeitung. Dresden, 1897.

The product obtained by reeling is known as raw silk and differs from threads of cotton, flax, wool, and other textiles in that it consists of continuous filaments.

After reeling the silk passes through the operation of throwing (twisting and doubling), scouring, and dyeing.

The waste product from the reeling process, as well as imperfect and punctured cocoons or cocoons injured by disease, are cleaned and spun by a process similar to that employed in the manufacture of yarn from wool and vegetable fibers. This spun product is known as **Florette Silk.**

Silk fibers in order to reach their perfect condition must be treated with hot-soap solution or "scoured," thus removing the sericin and rendering the fibers flexible and lustrous. For some purposes the silk is only half scoured. Instead of scouring, the silk may be treated by a process known as "soupling," whereby the fibers are improved in appearance without serious loss of weight. After warming at 25–30° C. in 10 per cent soap solution to render the fibers pliable and bleaching with dilute aqua regia, or sulphuring, the silk is soupled, i.e., treated very cautiously with potassium tartrate or else with hydrochloric acid, magnesium sulphate, or sodium sulphate.

STRUCTURE AND COMPOSITION OF SILK.[1]

Silk fibers, as appears from what has been stated, consist of two different substances: **Fibroin**, the horny, sulphur-free substance forming the fibers, and **Sericin**, or silk glue, the secretion of the anterior glands. The latter, when dry, is brittle, rough, cracked, and wrinkled, and must be removed in order to bring out the fine luster of the fiber. In unscoured raw silk the filaments are cemented together with sericin, while in the scoured product the filaments are separate and free from cementing material.

Silk is mounted in water for microscopic examination. Even the beginner will soon notice that the fibers, owing to their origin, lack all cellular structure and will readily distinguish them from all other textile fibers. The double fibers of unscoured silk (Fig. 110, *a–c*) bear on the surface swollen masses, flakes, or granular accumulations, or else are covered with a wrinkled and cracked envelope. These consist of silk glue. Comparatively few of these sericin masses are found on fibers from the middle layers of the cocoon (*a*), but the fibers of the inner papery layer, or parchment (*c*), are encased in such a thick layer of sericin that the latter forms a wrinkled, swollen, often cross-fissured tube. According to the investigations of v. Höhnel, these phenomena are due to the contraction of the fiber during solifidication, which causes the formation of folds and cracks in the sericin. He further states that cross-fissures are formed by the bending and elongation of the very elastic fibroin core, thus breaking the sericin into short cylinders which, after the fiber has sprung back to its original length, show the lines of rupture. These

---

[1] v. Höhnel: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905. 200.

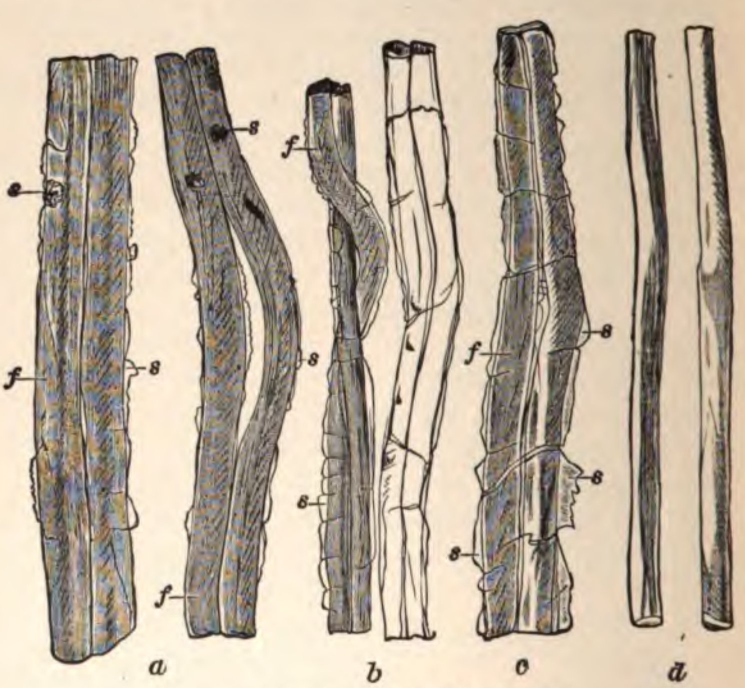


Fig. 110. True Silk. (T. F. Hanausek.)

a fine Italian organzine silk, unscoured; *b* florette silk from outer tangle of fibers; *c* florette silk from inner parchment layer; *d* fine organzine silk, scoured; *f* brins (individual fibers); *s* sericin coat.

eculiarities are most conspicuous in florette silk, made from the inner ocoon layers or parchment (*c*), the sericin coat forming a ground mass which are embedded the fibroin fibers.

Cross-sections of fibers from different parts of the cocoon also show arked differences in shape. While the cross-sections of the ultimate bers (brins) from the middle layer are nearly round or half round, those f the flóss or parchment are flattened on one side, or are even triangular ith the narrow sides of the two brins of a double fiber (bave) together. ot uncommonly the parallel course of the brins is interrupted; one of hem may bend outward (Fig. 110, *a*, right), leaving an empty space etween the two, or again one of the brins, owing to its more rapid secre-ion, may wind spirally about the other (Fig. 110, *b*, left). Then, too, n parts of the baves no sericin at all is distinguishable.

In the examination of unscoured silk the beginner should guard against istaking the two brins for the wall, and the dark line of separation for he lumen, of a fiber cell. The structureless homogeneous mass of the rins, the cylindrical form of which in the best silks may be clearly seen y raising and lowering the microscope tube, as well as the separation f the two brins on boiling in soap solution, serves to make the true nature f the fibers evident.

Scoured silk consists of isolated brins, although here and there the two embers of an original bave are found side by side. A brin may be ompared to a solid rod with a smooth lustrous surface and a more or ss uniform diameter. Constrictions occur here and there, and small umps are also occasionally evident. There are almost never any indica-ions of structure. The breadth of the brins from the middle layer of he cocoon is 10–21μ, mostly about 16μ.

The microchemical reactions of silk are so characteristic that this ber can be distinguished with the greatest certainty from other textile ibers.

Concentrated sulphuric acid dissolves silk completely; sugar and ulphuric acid color it red, thus showing the presence of proteid matter.

Boiling hydrochloric acid dissolves the fibroin in half a minute, while he sericin remains behind as a swollen tube (see Wild Silks). Nitric cid colors silk a yellowish tint, and picric acid imparts a permanent ellow to both silk and wool. Cuprammonia dissolves silk slowly.

WILD SILKS.[1]

The caterpillars of various tropical species of moths yield textile fibers, of which the most important are yamamai silk, produced in Japan and China by *Bombyx Yamamaya*, and tussah silk, from several Indian species. Mention should also be made of ailanthus silk, obtained in India from the caterpillar of *Attacus Cynthia*, and the silk from the Soudan species *Bombyx Faidherbii*.

TUSSAH SILK.—Among the species producing this valuable silk are *Bombyx Selene* and *B. Mylitta*. The fibers, like florette silk, are spun into yarn and are never obtained by reeling. The color is a striking, natural gray-brown which can not be removed and unfits the fibers for dyeing any but a dark color.[2]

MICROSCOPIC STRUCTURE.

Wild silks taken collectively may be distinguished from true silk by the presence of numerous, very distinct, longitudinal striations (Fig. 111), also by their greater breadth (40–60μ). These striations were long since observed, but not understood until v. HÖHNEL, in his important investigation, found them to be due to fibrillæ and air canals. The fibroin fibers (brins) are made up of numerous exceedingly fine threads or fibrillæ embedded in a ground substance, the latter being the more easily soluble in chromic acid. These fibrillæ form the light striations, while the darker and more distinct striations are due to air canals of various sizes, which can be accurately studied only after treatment of cross-sections with chromic and sulphuric acids.

If, as recommended by v. HÖHNEL, the sections are first colored with concentrated chromic acid, then washed somewhat and soaked in dilute sulphuric acid of proper concentration, the fibrillæ remain a yellow-brown color and do not swell, while the ground substance becomes colorless and swells greatly. In this manner ground substance, fibrillæ, and air canals may be clearly differentiated.

Not infrequently a fiber is marked by diagonal parallel lines (Fig.

---

[1] v. HÖHNEL: Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 214.

[2] According to PERNY, silk is obtained in China by reeling from the oak silkworm (*Saturnia Pernyi*).

111, *k*), due to the pressure of another fiber formerly in contact with it. These markings are highly characteristic of tussah silk.

Hydrochloric acid dissolves tussah silk and related wild silks only after boiling two minutes. V. HÖHNEL finds that the best reagent for separating real silk from wild varieties is a solution of chromic acid saturated in the cold and diluted with an equal volume of water. Only real silk is dissolved by this reagent. Moderately strong potash solution acts in the same manner.

Viewed with polarized light, silk displays characteristic colors. With crossed Nicols common silk appears bluish or yellowish cream-colored both on the broad and the narrow side. In places where the thickness of the fiber varies, other colors such as blue, green, or red make their appearance. Since in tussah silk the thickness of the fibers shows extraordinary variations, the broad side displays all the interference colors, the narrow side, however, because of its great thickness, only light colors (light rose and light green) in elongated patches.[1]

OTHER WILD SILKS.—Silk from *Saturnia pyri* and *S. spini*, natives of Europe, is sometimes used in mixtures. The fibers are partly smooth, like those of common silk, partly finely striated, and are intermediate in appearance between common silk and the wild silks of the East.

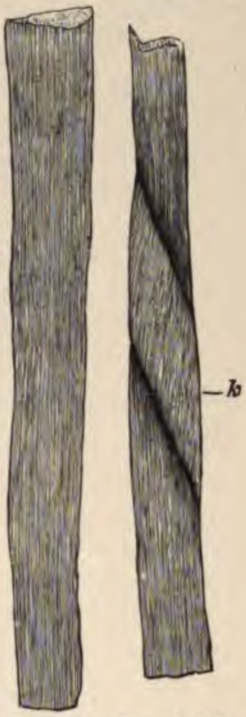


FIG. 111. Tussah Silk. (T. F. HANAUSEK.) *k* impression of another fiber previously pressed against it.

SEA SILK.

Certain marine mollusks, such as *Pinna nobilis* and other species of *Pinna*, possess a slender, worm-like foot with a gland which secretes numerous brown, somewhat woolly fibers 4–6 cm. long, forming the beard (*Byssus*). From these fibers, known as "sea silk", the inhabitants of southern Italy and Normandy make various small braided and woven articles.

---

[1] For further details see V. HÖHNEL: *loc. cit.* 217–219.

Sea silk is distinguished from all insect silks by the presence of natural ends (Fig. 112, *e*), which are rounded, and sometimes, in addition, somewhat expanded to form a small head. The fibers are both narrow (18-25μ) and broad (usually 40-60μ; according to v. HÖHNEL, up to 100μ). They are flat or elliptical in cross-section and often twisted, the narrow sides appearing darker than the broad sides. Exceedingly delicate longitudinal striations are present. The fracture is more or less even, or in steps, but is never fibrous. The thickness is often evident from the fractured surface. Particularly striking are the very narrow fibers which branch off from broad fibers (*m′*). A deposit of variable thickness, consisting of small brown granules, may often be observed.

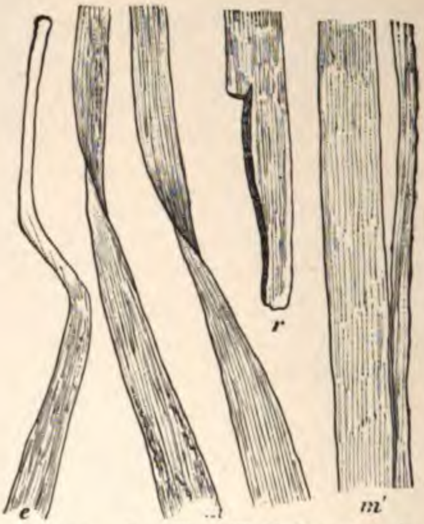


FIG. 112. Sea Silk. (T. F. HANAUSEK.)
e end piece; *m* broad twisted fibers; *m′* broad fiber with narrow branch; *r* torn end.

SINEW FIBER.[1]

Attention has been called in recent years to a fiber material of animal origin, which appears to be spun with other textiles, notably wool and hemp. It consists of fibers from animal sinews.

The material in the possession of the author consists of an almost woolly mass of broad, silky lustrous, narrow, often branching fibers. The sinews, which are developed at the ends of attachment of the muscles, are of string-like fibrous connective tissue consisting of wavy elements united in bundles of the first, second, and third degrees. Under the microscope sinew fiber is easily recognized by the regularly undulating fiber bundles. Yarn spun from sinew fiber and wool has great tensile strength and is somewhat rough to the touch. The length of the technical fibers depends on their fineness or, in other words, on the extent to which these elements have been separated, as well as on the length of the original sinews. Coarse fibers of the size of medium hemp fibers reach a length of 18 cm.; finer fibers, which are rough because of protruding elements, are at the most but 3–4 cm. long. In mixtures with white wool the coarser sinew fibers are evident because of their striking silky luster. In mixtures of sinew fiber and hemp the two may be readily distinguished by the naked eye, the sinew fibers being white, silky with a dazzling luster; the hemp fibers, gray-yellow.

---

[1] T. F. HANAUSEK: Mittheil. k. k. Tech. Gewerbe-Museums in Wien, 1905. The utilization of sinew fibers, as v. HÖHNEL states (*loc. cit.*, 200), dates from earliest times. The ancient Israelites in their religious rites used, under the name of "gidden", yarn twisted from sinews.

ARTIFICIAL SILK.[1]

The statements in this sub-chapter as to the manufacturing processes, the extent of the industry, and the nature of the product are based on articles by Dr. M. G. LUFT,[2] Technical Director of the Industrial Fibre Co., Inc., Cleveland, Ohio.

The idea of imitating silk originated with RÉAUMUR in 1734 but was not realized until toward the end of the nineteenth century. To-day the world's production of artificial silk is greater than that of natural silk and is rapidly increasing. Both production and consumption are greatest in the United States.

CELLULOSE SILK (RAYON).—These are generic names for fibers produced by dissolving cotton linters or purified wood pulp, with or without chemical treatment, in a solvent, forcing the viscous solution through minute orifices (spinnerets), removing the solvent, and otherwise treating to secure a cellulose filament.

Nitrocellulose Processes.—In 1855 ANDEMARS secured a patent for drawing out filaments from a solution of gun cotton with a steel point. In 1884 CHARDONNET devised a process using spinnerets. Later he denitrated the filaments. Actual manufacture began in 1891.

---

[1] Rewritten, February, 1926. A. L. W.

[2] J. Ind. Eng. Chem. 1925, **17**, 1037; J. Chem. Education, 1925, **2**, 864.

In manufacturing Chardonnet silk, cotton linters are treated with nitric and sulphuric acids, washed, partially dried, dissolved in alcohol-ether mixture, and forced through glass spinnerets. The filaments are freed from the solvent by drying (dry system) or passed through a setting tank (wet system). In either case they are twisted into threads, denitrated by sodium hydrosulphide, washed, and bleached.

Lehner silk is also a product of nitrocellulose, now prepared by a process similar to that for Chardonnet silk.

Cuprammonia Processes.—SCHWEITZER found in 1857 that cellulose is soluble in an ammoniacal solution of cupric hydroxide. DESPAISSIS utilized this solvent in 1890 but PAULY in 1897 was the first to begin actual manufacture.

The purified cellulose, whether wood pulp or linters, is mixed with cupric hydroxide and concentrated ammonia water. The solution of the cellulose thus obtained is filtered and forced through spinnerets into a setting bath of sulphuric acid or sodium hydroxide or first into one and then into the other. After thorough washing and bleaching, the filaments are treated like other kinds of artificial silk.

Thiele's cuprammonia process was much used in Europe before the viscose process was introduced but now has been largely displaced.

Viscose Process.—About 80 per cent of the world's product is made by this process based on the discovery in 1892 by CROSS, BEVAN, and BEADLE of sodium cellulose xanthate.

It is made from cotton linters or bleached spruce pulp. In the latter case the sheets are treated with 18 per cent sodium hydroxide and the excess squeezed out in hydraulic presses. The soda cellulose is shredded, aged, and treated with carbon bisulphide in rotating drums, thus forming yellow-orange crumbs of cellulose xanthate. The water solution is ripened, filtered, freed from air in a vacuum, and forced through platinum spinnerets into a bath of sulphuric acid and other chemicals where the streams are coagulated. The filaments are twisted into yarn, sulphur by-products are removed by sodium sulphide and bleaching with chlorine and the latter removed by antichlor.

The yield of rayon, selling at $2 per pound, per ton of sulphite pulp, costing 5 cents per pound, is about 1500 pounds.

Physical Characters of Cellulose Silk (Rayon).—In strength and elongation viscose is somewhat superior to nitrocellulose silk and the latter to cuprammonia silk. All three lose in strength and increase in volume when wet but on drying return to their original condition. They withstand boiling water and do not, like silk, rot or turn yellow with perspiration. The high absorptive capacity for perspiration is an advantage.

Rayon is more lustrous than silk because of the flatter filaments, but the luster differs, nitrocellulose silk being shiny, cuprammonia silk glassy, and viscose silk silvery. The luster and " feel " of viscose silk approach most nearly those of natural silk. Like linen and cotton, rayon burns without a decided odor or leaving a charred mass and is insoluble in 40 per cent sodium hydroxide.

CELLULOSE ACETATE SILK (CELANESE OR LUSTRON).—This consists of one or more acetic esters of cellulose. The process, patented by CROSS in 1894, has been improved by MILES and DREYFUS BROTHERS.

Bleached cotton linters are dissolved in a mixture of acetic anhydride, glacial acetic acid, and sulphuric acid, and the mixed acetates are precipitated with water, washed, dried, dissolved in acetone, and the filtered viscous solution is forced through spinnerets. The product is expensive, does not dye so readily as cellulose silk, and has a lower capacity for moisture absorption.

GELATIN SILK (VANDAURA SILK) consists of gelatin filaments hardened by formaldehyde. It has never reached commercial importance.

MICROSCOPIC STRUCTURE.

Authentic samples, kindly furnished by Dr. LUFT, showed certain differences in physical characters as noted below. While by color reactions the artificial silks are readily distinguished from natural silk, wool, cotton, and linen, also cellulose silks from cellulose acetate silk, the distinction of the three types of cellulose silk from each other is more uncertain.

PHYSICAL CHARACTERS.—Although the four types show individual characteristics, some of these may be due to treatment not peculiar to the process. The flattening and the nature of the channels and striations determine in large degree the character of the luster. The shape of the cross sections, best made after embedding and cutting with the microtome, furnishes a topic for investigation.

Channels and Striations.—The filaments made by the nitrocellulose process show false lumens, due to channels or incurved edges, the breadth about equaling that of the single false walls. Fig. 113, 2 and 3, of Chardonnet silk made about 1900, shows clearly false lumens and the incurved edges that appear like cell walls, as well as other details noted in the legend.

The filaments of cuprammonia silk are round, smooth, uniform, and remarkably free from false lumens and striations. The noticeable peculiarities of viscose silk are the flattened form and numerous longitudinal striations. In cellulose acetate silk false lumens are present but are narrower than in cuprammonia silk.

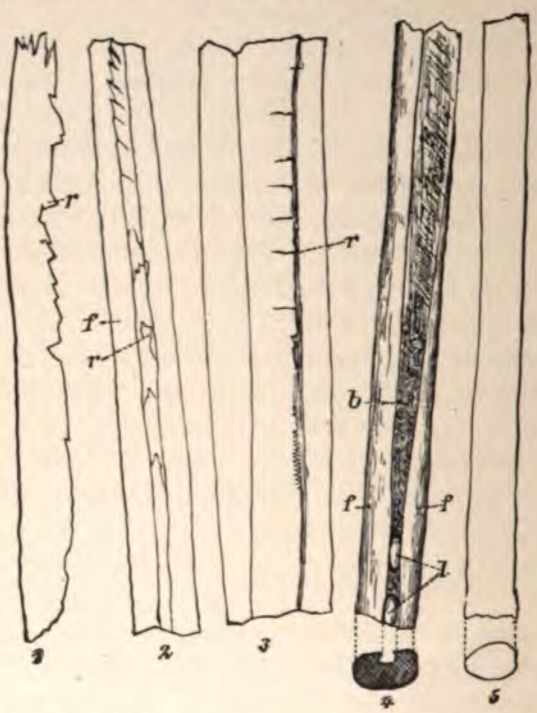


FIG. 113. Artificial (Chardonnet Process) Silk. (T. F. HANAUSEK.)

The fibers are colored violet by iodine in potassium iodide, showing that they are probably cotton collodion. *1* fiber seen on narrow side, with saw-teeth and rifts caused by stretching.—*2* fiber seen on broad side, showing false canal and saw-teeth at *r*.—*3* very broad fiber only slightly mutilated.—*4* uninjured fiber with beginning of false canal: *l* air bubbles; cross-section at the bottom.—*5* uninjured very narrow fiber without false canal; cross-section at the bottom. *f* induplicate edges; *b* the broad side between the induplicate edges.

Polarization Phenomena.—With polarized light nitrocellulose silk shows a strong play of colors while cuprammonia silk shows a feeble play but on rotating the analyzer the fibers change from one complimentary color to the other. Viscose silk acts similar to cuprammonia silk but the colors are weaker. Cellulose acetate silk is inactive with polarized light.

COLOR REACTIONS.—If the presence of dyes interferes with applying these tests they must be removed by bleaching or by solvents.

Iodine in Potassium Iodide.—v. HÖHNEL, HASSACK, and HANAUSEK describe the colors produced by this reagent which agree reasonably well with those obtained on Dr. LUFT'S samples. HANAUSEK, after noting the color with the reagent, adds "paper sulphuric acid" (p. 105); this, however, seems to have no advantage over mere dilution.

All the three types of cellulose silk on mounting with the reagent give a dirty violet red, becoming nearly black on standing a few minutes, while the cellulose acetate silk gives a bright yellow becoming orange on standing. On drawing water under the cover glass cellulose silks become a bright blue, then paler, and finally colorless, while the cellulose acetate silk does not change materially. Cotton and linen take on a dirty light violet red color which does not materially darken and disappears on dilution without forming a blue color. Natural silk and wool become bright yellow, not changing with standing or dilution.

Chlorzinc Iodine gives colors similar to those with iodine in potassium iodide but darker and the deep blue of cellulose silks on dilution is more intense and persists for hours.

Safranin in Water.—A few fibers are placed in a drop of 0.1 per cent aqueous solution of the stain on a slide, allowed to stand about 15 minutes, and either examined directly or better after washing out the excess of stain. All three cellulose silks stain a brilliant cherry red while the cellulose acetate silk takes on a faint pink color. Cotton and linen become a light dull red without a marked blue tinge while silk and wool stain a dull but deep cherry red.

Methyl Green in Water.—Treated as described in the foregoing section, but substituting a 0.1 per cent methyl green solution for safranin solution, nitrocellulose silk stains a medium green, viscose silk a light green, while cuprammonia and cellulose acetate silks stain hardly at all. Cotton and linen also stain a faint green while silk and wool become a brilliant green.

Methyl Green in Alcohol.—The fibers are soaked in a covered dish with a few cc. of a 1 per cent alcoholic solution for 15 minutes, washed in alcohol, and mounted in water. Cellulose acetate silk becomes a brilliant green color but cellulose silks and natural vegetable and animal fibers remain colorless.

Chemical Tests as used by The Industrial Fibre Co. follow:

(1) Burn a small portion of the sample. Cellulose silks burn very rapidly and leave no ash. Cellulose acetate silk burns slowly and leaves a charred bead. In neither case is an odor like that of burnt wool produced.

(2) If no charred bead is formed on burning treat the fiber on a watch glass with 3 cc. of concentrated sulphuric acid to which has been added two or three crystals of diphenylamine. Nitrocellulose silk turns a deep blue.

(3) Treat the fiber with 2 cc. of concentrated sulphuric acid on a watch glass, allow to react 5 minutes, and note the color. Viscose silk turns deep brown whereas cuprammonia silk becomes yellow. Run tests on known samples for comparison.

III. MINERAL FIBERS.[1]

Under this head we need consider only the materials known under the general name of **ASBESTOS.** Mineralogically there are two kinds: (1) true or hornblende asbestos, and (2) serpentine asbestos or chrysotile. The latter is most used and is obtained chiefly from Quebec, Canada; the former is mined in the province of Salzburg (Gastein Valley). According to LEPPLA,[2] Cape asbestos is made into fire-proof ropes.

The detection of asbestos in yarn or fabrics by microscopic examination is exceedingly easy. It is either in the form of single fibers or bundles of fibers. The single fibers are so fine that many of them can scarcely be measured under the microscope with ordinary powers. Fig. 114, *C*, shows one of the finest asbestos fibers, about 0.5μ in diameter, and for comparison a cotton fiber (*D*) 24μ broad, both magnified 700 diameters. The cut of the cotton fiber is 17 mm. broad in the line *a–b*, which corresponds to 24μ. This illustration shows more strikingly than the mere figures the enormous difference in size of the two fibers. Furthermore, asbestos fiber is uniform in structure and strongly refractive. The material also contains narrow, prism-like bars (*B*) and bundles of fibers showing longitudinal striations (*A*), both forms often being fringed at the ends. The bundles often are of a light yellow color. No vegetable fiber is anything like so fine as the strands of asbestos; of the animal fibers the secretion of certain spiders and possibly fibers of connective tissue (sinew fibers) approach it in fineness.

---

[1] T. F. HANAUSEK: Mittheil. k. k. Tech. Gewerbe-Museums in Wier, 1905.

[2] LUEGER: Lexikon der gesammten Technik. Stuttgart, 2. Aufl. 190 , **1**, 306.

It is also possible by microscopic examination to determine the kind of asbestos. Chrysotile is partly decomposed by hydrochloric acid and completely by sulphuric acid, provided sufficient time is allowed for the acid to act on the bundles; hornblende asbestos is not appreciably acted on by either acid.

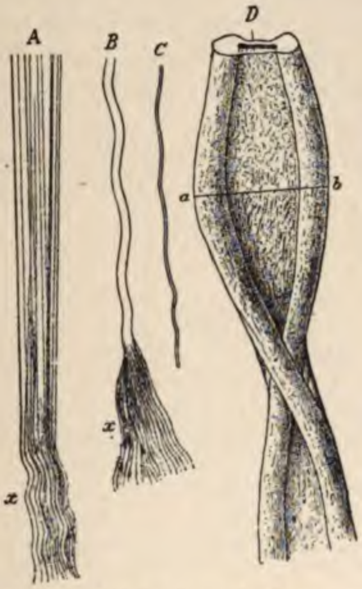


FIG. 114. Asbestos. (T. F. HANAUSEK.)

A a thick asbestos bundle, with fibers united except at *x*, where they form a brush end. *B* an asbestos prism (individual fibers not shown) with brush end at *x*. *A* and *B*, × 200.—*C* a fine asbestos fiber 0.5μ broad. *D* a cotton hair, 24μ broad in the line *a–b*, introduced for comparison. *C* and *D*, × 700.

IV. MICROSCOPIC EXAMINATION OF TEXTILE FABRICS.

Textile fabrics consist of threads at right angles to each other; the threads which run lengthwise in the piece form the **Warp**, and the thread or threads which runs crosswise forms the **Woof** or werf. In weaving, the woof is carried by the shuttle alternately to the left and to the right, and consequently at the selvage doubles on itself. Given a selvage edge, it is always a simple matter to distinguish the warp from the woof.[1]

---

[1] The technical microscopist should have a good general idea of the technology of spinning and weaving, since thereby he will be in a position to judge as to the effects of these processes on the fibers.

The multifarious variations in the arrangement of the warp and the woof give rise to

Lacking the selvage edge, the woof of loosely woven fabrics can be distinguished from the warp by the fact that the cloth stretches more in the direction parallel to the course of the woof threads.

Fabrics are designated according to the raw material as cotton, linen, hemp, jute, woolen, silk, and various mixtures of these.

Microscopic examination is really a qualitative analysis to determine the constituent fiber or fibers. Both the woof and the warp must be separately examined. For this purpose a piece 1–2 cm. square is cut out and separated into its component fibers, taking care not to mix the threads of the warp and the woof. If the first square does not contain all of the different fibers present in the fabric, other squares must be cut out and examined.

---

a number of distinct kinds of fabrics, which may be divided into four classes, brief descriptions of which follow:

I. *Plain Fabrics.*—This, the simplest form of fabric, has the woof thread run over one thread of the warp and under the next, and so on across the fabric. In most cases, as, for example, ordinary muslin, each thread of the warp runs alternately above and below the woof; in certain gauze-like fabrics, however, every other one of the warp threads is entirely on the upper side of the fabric, while the alternate threads are entirely below. This latter weave is secured by twisting the two adjoining warp threads after each stroke of the bobbin.

II. *Twilled Fabrics.*—The woof thread crosses on one side of two or more warp threads in succession and thus forms on the fabric continuous or broken diagonal rows. The simplest form is the regular three-leaf twill, in which the woof passes under two and over one thread of the warp, and so on across the piece. In regular four-leaf twill the woof passes under three threads and over one; in five-leaf, under four and over one; and so on. All of the foregoing have the warp predominating on the upper and the woof on the under side; if, however, the woof passes over and under the same number of warp threads, the fabric is the same on both sides. This latter is known as Batavia twill. Diagrammatic representations of regular three-leaf twill and four-leaf Batavia twill follow:

<table>
<tr><td>- | | - | | - |</td><td>| | - - | | - - |</td></tr>
<tr><td>| - | | - | | -</td><td>- | | - - | | - -</td></tr>
<tr><td>| | - | | - | |</td><td>- - | | - - | | -</td></tr>
<tr><td>- | | - | | - |</td><td>| - - | | - - | |</td></tr>
<tr><td>| - | | - | | -</td><td>| | - - | | - - |</td></tr>
<tr><td>Three-leaf twill.</td><td>Batavia four-leaf twill.</td></tr>
</table>

(Horizontal lines woof; vertical lines warp.)

Satin may also be considered a twill with the warp threads mostly running above the woof, thus giving the surface a smooth, shining appearance.

III. *Figured Fabrics.*—These have more than two, usually numerous, combinations of threads, thus forming a more or less intricate design. By means of different-colored threads these designs are made still more prominent.

IV. *Piled Fabrics,* including velvet and plush, have a dense coat of erect or appressed fibers on the upper surface. In true silk velvet the pile is formed by cutting extra threads of the warp woven over the true warp; in imitation velvets the pile threads are woven with the woof.

Warp and woof of linen cloth should be qualitatively and quantitatively the same, that is, they should both be pure linen and the threads should be of the same size. Muslin (cotton cloth) should be uniform throughout, both threads consisting of the same kind of cotton, with no noticeable difference as to the length and diameter of the fibers, the number of dead hairs, etc. The examination of woolen cloth, with reference to the kind of wool or hair, is more difficult, especially if the fibers are dyed. Details are given in the chapter on animal hairs.

Whether a fabric purporting to be silk is all silk, or part silk, may be easily determined by microscopic examination. For example, half-cotton grosgrain silk consists of silk warp and a cotton woof; in certain silk fabrics the warp is reeled silk, the woof spun silk, etc.

Quantitative methods depend on the difference in solubility of the silk, wool, and vegetable fibers.

Practical Examples.[1]

1. A piece of cord, found in the house of a man suspected of being an incendiary, resembled a piece of fuse found near the scene of the conflagration. Both pieces were examined microscopically to determine whether they could have been parts of the same cord.

The fuse was made up of three strands, each spun from hemp. The cord found at the house of the suspect was also of three strands, but two were of hemp, while the third was of jute. Even while twisted in the cord the jute strand was obviously different from the others, owing to its lighter gray-yellow color, its greater luster, and the tow-like appearance due to the separation of the individual fibers, a phenomenon which I have always insisted is especially characteristic of jute.

I was accordingly justified in reporting that the two pieces of cord were not from the same cord, thus removing a grave source of suspicion.

It may be noted in this connection that the use of a jute strand in a hemp rope is an adulteration, or at least a substitution of raw material of inferior value.

2. A deer snare on which reddish spots were visible, and a piece of cord, also with reddish-colored spots, from the leather bag of a carpenter suspected of poaching, were submitted for examination to settle the following points: (1) were both cords identical, (2) was the color the same in both, and (3) were both so-called "carpenter's cord"?

---

[1] See Technisch-mikroskopische Untersuchungen. Mittheil. k. k. Tech. Gewerbe-Museums in Wien, 1905.

Investigation showed that the deer snare consisted of four twisted to the left, and each strand of two smaller strands also to the left. All the strands were of hemp with fibers in good pr tion. Tannin ducts were present in abundance, and the ends of th fibers were mostly entire. All these characters indicated that th was made of "carpenter's cord".

The cord from the bag was a so-called "sugar cord", consis three strands twisted together to the right; each strand, howeve twisted to the left. All the strands were of hemp, but the fibe bleached from use and were greatly mutilated.

It was thus proved that the two pieces were of an entirely d kind and of different origin.

The spots on the snare gave, on boiling with hydrochloric acid, fi and adding potassium ferrocyanide solution, a considerable am Prussian blue, and therefore must have been iron oxide; the spots second piece gave no iron reaction.

3. The following example illustrates the kind of difficult, often able, problems encountered by the technical microscopist.

A wad shot from a muzzle-loading gun found at the scene of a and the wadding from the coat of a man suspected of being the m were submitted for examination to learn if the two were alike in co tion. The lining of the coat was torn in one place, and part of the w beneath was missing. Microscopic examination showed that both t wad and the wadding from the coat were exactly the same, and co of very crude cotton containing fragments of the epidermis wit attached, many inferior, thin-walled, snarled, short cotton hairs, addition, waste linen threads, small reddish particles of feathe Although the identity of the two materials seemed highly probable, merely reported that the two samples were of the same material a tained the same impurities; therefore it was to be inferred that t wad was made from the wadding, but it might not have been mad the wadding taken from this particular coat, since the same waddi doubtless used in many coats.

4. The officials at a certain custom-house were unable to a some samples of white and yellow yarn, owing to the lack of an a designation. If I remember rightly, the material was declared "Chinese yarn".

The yarn consisted mostly of single sclerenchyma fibers of co able breadth (up to 80–82μ), with pointed and blunt ends and a lumen. Cross-sections were elliptical or flattened. The cell walls displayed in longitudinal view numerous longitudinal clefts and cross-dislocations, and in cross-section radial clefts. The material was thus shown to be ramie yarn.

5. A piece of linen cloth of medium fineness was submitted for examination by the purchaser, who, owing to the low price, regarded it with suspicion. Both threads consisted of flax fibers, among which were numerous relatively short fibers with broad lumen and more or less rounded ends, resembling hemp fibers. Since none of the fibers had forked ends and none of the accompanying tissue elements of hemp were present, while, on the other hand, fragments of the epidermis of the flax stem were detected, the conclusion was reached that the admixture was not hemp yarn but tow yarn.

6. A sample of plush was submitted to learn whether it was made from mercerized cotton or linen. Four kinds of threads were isolated—*a*, *b*, *c*, *d*: *a* consisted of unaltered cotton; *b* was twisted from two threads, part of the fibers being treated cotton; *c*, the thread on both sides of the pile on the face side, was also twisted from two threads and had a brilliant luster—it consisted of mercerized cotton; the pile *d* consisted of linen, partly single fibers and partly groups of fibers, the latter often being covered with remnants of the epidermis. What was especially remarkable was the fact that the number of isolated linen fibers far exceeded the normal, hence the marked silky luster of the pile. In the manufacture of this fabric the fibers must have been more carefully heckled than is customary even with the finest grades of linen.

7. An alleged linen fabric, on account of its gray-yellow natural color, was suspected of containing jute. Investigation showed the complete absence of jute—tests for lignification gave negative results—but, on the other hand, it was found that the fabric was made from tow yarn. It was reported that the sample was a smooth, linen-like, unbleached fabric made from tow yarn and suited for sacking, toweling, and similar uses. This decision explained the gray-yellow color. There was no evidence of an admixture of jute.

It may here be stated that since 1903 a fabric has appeared in commerce under the name of " Silvalin ", which has been used for sacking in place of jute sacking or burlap. The author has seen the statement in a trade report that this sacking has given excellent satisfaction; it is little affected by transportation from one end of the earth to another and repeated filling, in fact is in every way serviceable. Silvalin contains 50 per cent or more of sulphite cellulose and cotton.

8. The reason was sought why press cloth impregnated with cuprammonia tore after fourteen days' use, whereas formerly cloth of the same quality lasted 1–1½ years without tearing. It was stated that chemical investigation gave no clue to the trouble and that perhaps microscopical examination might disclose the reason.

At the outset it was obvious that an absolutely certain solution of the problem was scarcely possible. First, the cloth previously used for a long time should have been available for investigation, so that it could be determined whether the raw material was in all cases the same. Further, it was necessary to determine whether the method employed, the pressure, etc., had not been changed. Due regard was given these points in the report, which, as it may be of use in other cases, is here given in detail:

The warp is of three threads, the woof of four, both being well twisted; the cloth itself is a linen-like, smooth fabric of close, but simple, weave. Microscopic examination shows that both warp and woof are entirely of cotton, furthermore that the cotton fibers are swollen, which is distinctly evident at the torn ends, and that here and there fibers show diagonal cross-fissures and jagged cleft ends from which the cracks often extend far inward. Adhering to numerous fibers are small mineral granules which are soluble in large part in hot water. The swelling phenomena are intensified somewhat by warming a water mount. The cotton shows then (1) distinct swelling, also (2) evidence that the fiber has been strongly mutilated by pressure, strain, etc. The cloth is covered with a greenish-white, dust-like coat, the dry copper compound.

Conclusions.—The tearing of the press cloth during use must be due to one or more of the following causes: (1) very inferior or refuse cotton used in making the cloth; (2) improper methods of manufacture of the yarn and fabric; (3) great increase in pressure to which the cloth was subjected; (4) subsequent change of the cotton due to physical or chemical influences.

(1) Examination even of the swollen and mechanically weakened cotton shows that the original cotton was of good quality. So-called dead and half-ripe hairs occur in no greater numbers than in a good grade of cotton. This cause then may be excluded.

(2) Yarn and fabric meet all the requirements which, from the technical standpoint, could be expected. Warp and woof are tightly twisted;

A gray mixed woolen was examined because of the alleged presence of shoddy or some other inferior material.

By brushing with a stiff brush there was obtained a very small amount of fibers consisting of white (or rather colorless), yellow, blue, rose-red, and red-brown hairs. Part of these hairs had normal, and part fringed, ends; the epidermal scales were all distinct, and 10 were present in each 100μ. These hairs were all from wool.

The woof threads were rough, yellowish gray, and contained three forms of hairs: (1) Colorless wool hairs without medulla, mostly with entire ends (seldom one end split) and epidermis intact; number of scales 10 in 100μ; breadth of hairs 15–40μ, those 30–40μ broad being most abundant. These hairs were sheep's wool. (2) Hairs dyed blue; like the preceding, also of sheep's wool. (3) Brown beard-hairs, 30–50μ broad, mostly having a broad medulla with distinct walls, strongly developed fiber layer, with accumulations of brown dyestuff in longitudinal streaks, and epidermal cells with thick edges. These hairs belong with the following. (4) Brownish wool hairs without medulla, 15–18μ broad, having high epidermal scales (6–7 in each 100μ), each scale diagonal on the edge with a tooth. Both (3) and (4) were camel's hair.

The warp had the same composition as the woof.

The examination of the fibers obtained by brushing indicated that a small amount of shoddy was present, but the fact that fibers differing in color from the others were found only here and there in the thread showed that the quantity of this admixture was inconsiderable. On the other hand, the fabric contained camel's hair, the quantity of this inferior fiber, as determined by counting tests, amounting to upward of 50 per cent. If the goods were claimed to be made from sheep's wool they must be classed as adulterated.

10. A sample of solid blue-black cloth was examined for shoddy. The cloth was rather thin, light, and soft, with a somewhat loose nap. Although no selvage edge was present, warp and woof were readily distinguished by the difference in the resistance to stretching; in the direction of the warp it stretched but little, but in the direction of the woof very considerably. With a stiff brush numerous short pieces of fibers, mostly wool hairs, were removed, which, since none of them had sharply cut-off ends, could not have been sheerings from cloth, a material often worked into the nap. Warp and woof were alike in composition. The fibers were 1–6 cm. long, but those 2–3 cm. long predominated. Examined in water they were seen to be wool fibers varying in color from light blue to blue-black, mixed with

occasional cotton fibers. After treatment with hydrochloric acid, the wool fibers were blue, red, violet, red-brown, and yellow-brown, the cotton fibers were colorless, blue, brownish, yellow, and red. On placing the fibers in warm potash, the wool fibers naturally swelled greatly and again displayed different colors such as deep blue, pale violet, brown-violet, and yellow-brown, while the cotton fibers were brown. Many of the fibers had fringed ends, and in addition some of the short ones were separated into the individual fibers of the cortex in other parts of the shaft. In the longer fibers numerous split and ravelled-out places were observed. The violet hairs were characterized by the absence of epidermal scales. Those which became red with hydrochloric acid were narrower (20–25μ), while the violet hairs were broader (30–36μ). Beard-hairs (with interrupted medulla) were only occasionally found. The ease with which the threads were torn apart, displaying short fibers, was striking. After numerous countings it was determined that there was one cotton hair to ten sheep's-wool hairs.

From what has been said it is clear that the tests were decisive, as they should be in order to reach a positive conclusion. Indeed, the presence of 10 per cent of cotton is proof that the cloth contained shoddy, since cotton is never present in good woolen cloth, while the different-colored fibers, seen after the dyestuff last employed was removed with hydrochloric acid, furnished confirmatory evidence. Further proof was furnished by the large preponderance of short wool hairs, the numerous greatly mutilated hairs with fringed ends and in many cases without epidermal scales, the marked difference in size and therefore in quality, as well as in color, of the hairs, and finally the ease with which the threads unravelled. With all this evidence the conclusion was reached that the sample was largely composed of shoddy.

11. The following illustrates the third question given under example 9: It was asked whether sample A contained raw material equal in quality to that in sample B.

The fabric designated A was a smooth, linen-like, woolen cloth characterized by a nap on both sides.

Warp threads: entirely of wool hairs without medulla, with sharply cut-off ends, but occasionally with brush ends; many of the hairs with irregular course, the difference in breadth often sharply marked, the hairs being, as a consequence, irregular. Average breadth, 17–20μ (a considerable number), 23–30μ (most of the hairs); number of scales in 100μ, 9 to 10. Isolated "dog hairs".

Woof threads: only medulla-free wool hairs with sharply cut-off ends, here and there with brush ends; occasional hairs with irregular course. Average breadth, 17–20μ (few hairs); more than half of the hairs, 23–30μ; the remainder, 30–40μ; number of scales in 100μ, 10–11. The woof threads were accordingly different from those of the warp, consisting of No. 2, No. 3, and No. 4 wool; notwithstanding this the woof threads had the smaller diameter.

Sample B was a three-leaf twill, stiffer, thicker, and denser than A.

Warp threads: fine and coarse hairs, partly with entire and partly with brush ends; here and there without epidermis; many short pieces without epidermis and with lamb ends; numerous hairs with mutilated fiber layer; colorless, brown, or yellow pieces; average breadth of the long hairs, 20–32μ; consequently mostly No. 3 wool. Shoddy was unquestionably present in the warp.

Woof threads: in general like those of the warp except that the short, variously colored hairs with brush ends were much more numerous, and beard-hairs were often visible in the fabric with the naked eye.

The conclusion reached is evident from the foregoing. Sample B—aside from being a twill and consequently an entirely different kind of fabric—was in composition radically different from A: it contained shoddy; furthermore, the wool was in general coarser. It was markedly inferior to sample A.

12. In the appraisal of fabrics in custom-houses, it is important to distinguish between those made from the natural wool of colored sheep and those made from dyed wool, the latter (in Austria) being subject to a higher duty. The questions which come up include usually three points: (1) Is the wool or yarn dyed, undyed, or mixed? (2) Was the dyeing done in the wool or in the yarn? And finally (3), How are light colors to be judged?

The distinction of natural-colored wool from dyed wool is not always as simple as is commonly thought, the two extremes, namely, light colors and dark colors or black, being especially difficult. In most cases the practiced microscopist can detect the coloring substance in the hairs, provided these are not entirely opaque. v. Höhnel[1] states as follows: "The natural color is chiefly contained in the fibers and medullary cells in a granular form. In the medullary cells the grains are mostly aggregated, in the fibers they are in longitudinal rows. Slightly colored hairs always have colorless walls. On the other hand, in dark-colored hairs the walls of the fiber cells are impregnated with coloring matter, and in artificially colored hairs the dye is always found in the walls, coloring them uniformly. Artificially colored hairs therefore do not show plainly the lumen, while in hairs with natural color this is the most conspicuous part. Natural wool is further characterized by the longitudinal streaks of pigment grains, which do not occur in artificially colored fibers."

---

[1] Mikroskopie der technisch verwendeten Faserstoffe. Wien, 2. Aufl. 1905, 165.

My own experience leads me to call especial attention to the fact that the dye of artificially colored hairs is so uniformly distributed as to form a solid color. This is due to the deposition of the dye, not only in the walls of the fiber cells (and also of the medullary cells, when present), but also in the cell contents and in the occasional, exceedingly small intercellular spaces. Distinction of very dark or black hairs is not, however, possible except after special treatment. The natural coloring substance is in a high degree resistant of chemical reagents, but if once partially removed, the rows of pigment granules become evident, thus furnishing the best means of identification of the natural color. Artificial colors are mostly removed or destroyed by caustic alkalies, acetic acid, and hydrochloric acid.

Two cops and 12 skeins of gray, brown, and reddish yarn were submitted. With regard to the first, it was asked whether the yarn was from dyed mixed wool or from natural-colored dark and light wool; with regard to the skeins, whether a mixture of dyed wools was present with the natural-colored mixed fibers.

One of the cops was dirty white, the other somewhat lighter. The yarn consisted of white sheep's wool with occasional brown or black hairs. Treated with boiling hydrochloric acid the black hairs in places became lighter; these lighter places were brown, not, however, uniformly brown throughout, but streaked with lighter and darker shades. The original brown hairs showed the lighter and darker stripes, which corresponded in transparency to the intensity of the coloring. On boiling the hair in caustic potash solution, the fibers exhibited the usual swelling, accompanied, however, by a partial solution of the color which colored the liquid brown; the brown hairs became lighter, while the black hairs remained deep brown until they began to swell. Exactly the same results are obtained with black or brown hairs of man, the ape, and the cat. Attention should be called in this connection to an important point. There is no black dye applicable to wool—at least the writer has no knowledge of such, either from experience or reading—which suffers no change in boiling hydrochloric acid or hot caustic alkali. Even aniline black, the best black dye, after treatment with acids, shows under the microscope a green shade or changes to green. From this it appears that the black and brown hairs were not dyed. The uniform coloring in stripes and streaks, which never occurs, or can occur, in dyed wool, is explained by the removal on boiling of that portion of the natural coloring material present in the cell wall, while the portion contained in the form of granules in the fiber cells remains more or less intact. The walls of the fiber cells, thus rendered colorless, together with the small intercellular spaces, form the light streaks; the cell lumens, with the granules, the dark streaks. On comparison with dyed wool this difference is strikingly apparent.

The 12 skeins, consisting throughout of alpaca, were also found to contain only natural coloring matter. Hydrochloric acid in no case produced a change; boiling caustic potash dissolved a portion of the brown or black color to a brown liquid and brought out the rows of pigment granules, which in alpaca are especially prominent, some rows becoming light-colored, others remaining deep brown.

The examination of light-colored wool is much more difficult and does not always lead to a positive conclusion.

13. Three cops and 2 skeins were sent for examination to determine whether they were made from natural or colored wool.

All the samples were of nearly uniform pale yellow or cream color. Under the microscope all the hairs appeared colorless with very slight yellowish tint, the medulla of the hairs being of the same color as the fiber layer. None of the reagents used in the examination of dyed wools extracted the color or changed its tone. Since the cream-colored tint of yarn and fabrics is often secured by soaking in an infusion of spent Chinese tea, tests were made with iron salts for tannin, but with negative results. Since neither microscopical nor microchemical methods gave evidence of artificial color, it must be concluded that the samples were made from uncolored wool.

14. This illustration shows how the coloring can be obscured by certain admixtures.

It was asked whether a certain sample of woolen yarn was dyed, or simply colored, or in its natural condition. The yarn was of a marked gray color, in parts with distinct yellow streaks, had a greasy feeling, and was roughened by very coarse, white, opaque beard-hairs. Examination showed that the hairs were mostly short, with smooth, sharply truncated ends. In water mounts it appeared that a yellowish material in layers, lumps, and balls formed a coating on the hairs, often covering them their entire length. This coating gave them the appearance of being dyed yellow. These masses consisted in large part of fat, as was proved by treatment with ether and potash. After dissolving the masses from the hairs the latter were mostly colorless; some, however, were yellowish, and a very few were brownish or distinctly brown. Both wool hairs and beard-hairs were present; the former were 10–50μ or more broad, the latter varied greatly in breadth, but were mostly broad with thin walls and a strongly developed medulla consisting of narrow medullary cells. The number of scales in 100μ was 5. These hairs were of angora wool or mohair. Here and there were also found other kinds of wool hairs, which, together with various foreign materials such as paper fibers, etc., must be regarded as accidental impurities.

The coloring matter of the brownish and brown hairs was not distributed uniformly over all parts of the hair, but was in granules and streaks and also in small pigment spheres. In hydrochloric acid the color was not altered; in potash the hairs swelled, while the brown coloring matter remained for a long time unchanged. Many beard-hairs had a yellowish medulla and an almost colorless fiber layer, which would be impossible for dyed hairs. Therefore it is safe to conclude that the hairs were not from dyed but from natural wool. The extraordinarily coarse quality of the wool was indicated by the fact that after cleaning, that is after removal of the fat, the color was not pure white. The gray-yellow color was due to the fat with which the wool was coated. When a bit of the wool was treated on a cover-glass with ether, and the ether, after removal of the wool, evaporated, there remained a fine yellow ring corresponding to the border of the drop, which consisted of the fats from the ether solution (palm oil). The yellow color belongs then to this fat and not to the fiber. The whole process could be followed under the microscope. A hair was selected on which lumps of fat were deposited, ether was added, and the solution of the fat, as well as the fact that the color of the hair remained unaltered, was carefully observed; on evaporation of the ether, the coloring matter of the fat collected on the edges of the drops. From the report rendered may here be quoted the conclusion, which points to an error on the part of the first experts: "The hairs are largely colorless; some, however, are yellow, brownish, or brown. The mixture employed by the experts to dissolve the coloring matter and clear the hairs consisted of hydrochloric acid, acetic acid, sulphuric ether, and alcohol, or, in other words, the same chemical substances used in our investigations. Their error lay in regarding the fatty matter, with its yellow color, which had been dissolved by the alcohol and ether, as belonging to the fibers. If they had made a careful microscopical examination they would have found that the color of the yarn was entirely due to the fat, the wool itself being entirely free from artificial colors."

15. Two samples of fabrics were submitted for comparison as to the fineness of the weave and the quality of the yarn.

In this connection it may be well to note that measuring the breadth of fibers is an important but exceedingly tedious undertaking. If, for example, I state that the variation in a given sample is from 18 to 23μ, these figures represent the extremes of fifty or more measurements of as many hairs. Naturally only one kind of hair, for example wool hair, is to be considered if one expects to secure accurate results; still there are exceptions to this rule, as is shown by one of the following examples.

The following results were obtained on the samples in question:

(1) *The Fineness of the Weave* of the two samples was practically the same as shown by the following figures, in which the numerator represents the number of threads of warp, the denominator the number of threads of woof.

A. In $\frac{1}{4}$ sq. cm. $\frac{12}{22 \text{ to } 23}$; in 1 sq. cm. $\frac{25}{44 \text{ to } 46}$; in $\frac{1}{4}$ sq. inch $\frac{16}{29 \text{ to } 30}$.

B. In $\frac{1}{4}$ sq. cm. $\frac{12}{23}$; in 1 sq. cm. $\frac{25}{46}$; in $\frac{1}{4}$ sq. inch $\frac{16}{30}$.

If in A the averages for the woof are taken the results would be, respectively, $\frac{12}{22.5}$, $\frac{25}{45}$, and $\frac{16}{29.5}$.

(2) *Kind of Weave.*—Both samples were three-leaf twills, much alike in general appearance, although A appeared to be somewhat the rougher.

(3) *Microscopic Characters.*—A. The warp is a good quality of pure cotton with occasional half-ripe hairs. Almost all the threads are covered with numerous small granules and rods resembling fungous or, perhaps, bacterial colonies.

The woof is of pure sheep's wool, consisting entirely of wool hairs (no beard-hairs—with medulla) which are sharply truncated on the ends (not fringed), almost free from bruises, and give with hydrochloric acid a uniform carmine-red color; breadth, 16–41μ, usually 18–23μ. It consists of fine merino between electoral, prime, and second grades. The broader hairs are rare, often without intermediate forms, therefore of a distinct class. The thickness of the yarn threads varies from 165 to 270μ.

B. The warp is of pure cotton as in A. The woof, as in A, is pure sheep's wool, becoming a uniform carmine-red on treatment with hydrochloric acid; breadth, 16–40μ. Under the microscope no especial differences were noted, except that transitional forms between the finest and coarsest hairs were present, but this distinction was not marked. The yarn threads were 170–220μ broad.

(4) *Fineness of the Wool Threads.*—Of A 12 meters weighed 0.163 g., or 73.64 m. 1 g. It is, therefore, according to the international system, No. 73, or, according to the English system (1 skein = 560 yards), No. 65. This corresponds to quality AA (fine merino).

Twelve meters of B weighed 0.154 g., or 77.92 m. 1 g. It is, therefore, as regards fineness, No. 78 international or No. 69 English.

It should be stated that these numbers, strictly speaking, are only relative, since wool and dye were weighed together; absolute values can be obtained only with undyed wool.

Conclusions.—The examination showed that the warp of both samples was cotton, the woof merino wool; that the sheep's wool showed only slight differences; that the wool threads were a little different in fineness, since A was No. 73 and B No. 78. The fineness of the weave was the same in both.

My report gave no recommendations to manufacturer or merchant as to the valuation.

16. A problem concerning the covering of telephone wires. Two wires were submitted to ascertain whether both were alike and from what material they were made. Sample A was covered with true silk; B, on the other hand, with mercerized cotton. These facts are interesting, since the covering is not merely for protection but for insulation. The case deserves further investigation from this standpoint.

17. An insurance company desired information in a somewhat peculiar case, namely, whether the holes in a lady's cloak were caused by fire or were eaten out by moths. The cloth was woolen, with black, blue, and white (colorless) hairs. The findings were as follows: Several small pieces of the cloth adjoining the holes were cut out with shears and examined microscopically. The tissue was of sheep's hairs, which were largely black and opaque; some, however, were blue or colorless. Even the colorless hairs were often browned and puffed up at one end. Among the black hairs could be found many with very broad ends, some being swollen

to three times their natural size, also parts of hairs fused together to form a homogeneous mass which could easily be reduced to a fine powder. These pieces were brown and showed on strong magnification no organized structure. When these were compared with hairs which were burned by holding close to a flame, it could be seen that both showed exactly the same phenomena.

The cloth about the holes was also carefully searched for remains of moths, such as the pupa cases and scales from the wings, but no trace of these was detected. Hairs partially eaten were also searched for, but none were found. The holes could not have been made by moths.

It was accordingly established beyond question that the holes were caused by fire.

18. An interesting problem concerned the nature of five samples of racket strings. These were submitted to determine whether they were made from gut. The result of the investigation was surprising. Only two consisted of gut; these on boiling broke up into five strands, each of which was a gut tube. The strings were dry, yellow, strongly twisted, not glassy or gelatinous, only slightly transparent, shrunk on boiling to one third their length, and swelled very considerably. The third sample appeared quite different. The strings were strikingly smooth, strongly lustrous, almost glassy, gelatinous, transparent; on boiling they did not shrink, but broke up into 50 fine threads of true silk which had been twisted and coated with glue preparation. In the fourth sample there was little evidence of twisting; the strings were very conspicuously smooth, strongly lustrous, glassy-transparent, pale yellow. They were difficult to cut and remained intact on simple boiling with water, but were separated into the constituent fibers on treatment with dilute alkali. They consisted of true silk, but in this case of raw silk with the two brins still united, the smooth glassy appearance being due to the glue with which the strings were impregnated. The fifth sample was radically different from the foregoing. The strings were much thicker, very stiff, glassy-gelatinous, almost transparent, lustrous, yellowish, indistinctly twisted, easily cut, with a homogeneous appearance. Boiled in dilute potash they yielded a thick, gluey mass which, heated dry, gave off the disagreeable odor of animal glue. Boiled in water the strings separated into thick, almost angular, colorless threads, which showed under the microscope very fine longitudinal striations. Iodine colored these threads yellow, sulphuric acid brown with very distinct striations. On standing in water twenty-four hours they became white, opaque, and separated into numerous threads which, on heating

with water under a cover-glass, immediately fused together on reaching the boiling-point. They were gelatin threads hardened, probably, with formaldehyde.

Of the five samples two were of real gut, one of true silk with surface glue, one of true silk with impregnating glue, and one of hardened gelatin threads.

CHAPTER IV.

STEMS AND ROOTS.

I. WOOD OF DICOTYLEDONS AND GYMNOSPERMS.

Wood in the strict sense of the term is the axis (and secondary axes) of trees, freed from the bark. As it is also customary to speak of the wood of roots, the wood of palms, bamboo wood, etc., the meaning of the term should properly be extended so as to include all hard and solid parts of the stem and root of the higher plants, excepting the outer enveloping tissues.

A consideration of the structure of vascular bundles will be found at the end of the chapter.

The importance of wood to the human race need hardly be emphasized. It is one of the most valuable of industrial materials, perfectly adapted for many uses. It is easily worked, and possesses to a greater or lesser extent a great variety of important properties, such as all degrees of solidity and weight, also toughness, elasticity, cleavability, durability, and so on. Although in recent years wood has been replaced for many purposes by other materials, notably iron, it is still indispensable for furniture, building, etc., and is essential for civilization.

For practical as well as for scientific reasons we will classify the woods used in the arts in three groups: (1) coniferous woods (wood of gymnosperms or conifers); (2) broad-leaved woods (wood of dicotyledons); (3) stems or "wood" of endogens (monocotyledons), such as palms, bamboo, etc. In this section only woods of the first two groups are considered.

The grouping of gymnospermous and angiospermous woods in different classes is based on marked physiological and anatomical differences.

The wood of the stem has two functions to perform, one purely mechanical, the other physiological. The mechanical function is to furnish support, the physiological to conduct soil water containing mineral salts in solution and to store up reserve material. It is of great interest to note what organs the plant employs in carrying on these functions.

In most gymnospermous woods both the mechanical support and the translocation of water are carried out by only one group of tissues, or, in other words, one kind of organ performs both functions. This is the simplest type of wood.

If, however, a distinct group of tissues of the wood performs each function, thus dividing the labor, we have a higher type of wood structure, corresponding to a higher stage of development of the group of plants. This is the case with the dicotyledons.

Since the technical properties of woods are dependent on the anatomical structure and chemical composition, and since, on the other hand, the characters of a wood determine its technical application, it is evident that a knowledge of the structure, as well as of the technical characters, is indispensable to the technical microscopist.

A. Structure of Wood.[1]

Disregarding all the irregularities which result from growth and various other influences, a tree trunk may be regarded as a geometric cone with its base at the earth and its apex pointed upward.

In order to understand the internal structure of a tree we must study three kinds of sections: (1) **Transverse** or **Cross-sections**, i.e., sections cut perpendicular to the axis of the trunk (Fig. 115, *iai*); (2) **Radial Sections**, i.e., longitudinal sections cut through the axis of the trunk (*aa*, *dd*); and (3) **Tangential Sections**, i.e., longitudinal sections cut parallel to the axis of the trunk.

First let us consider the striking characters observed in the three sections of a coniferous wood. The cross-section is more or less circular, with a special form of tissue in the center, known as the pith. About the pith are arranged concentric rings, of which those nearest the center are farthest apart, while those nearest the periphery are closely crowded together. These are known as **Annual Rings**. Aside from the annual rings and scattering dark specks, or resin pores (found in *Picea* and

---

[1] T. F. HANAUSEK: Holz. Lueger's Lexikon der gesammten Technik, **5**, 211. Nutzhölzer. *Ibid.*, **6**, 566. HARTIG: Die anatomischen Unterscheidungsmerkmale der wichtigeren in Deutschland wachsenden Hölzer. München, 3. Aufl. 1893. MOELLER: Das Holz. Cassel, 1883. K. WILHELM: Wiesner's Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903, **2**, 1.

Pinus, but not in *Abies*, *Taxus*, *Cupressus*, *Juniperus*, and *Thuja*), no details are evident to the naked eye. In the cross-sections of a broad-leaved wood, such as, for example, oak, medullary rays and wood parenchyma are also evident. The **Medullary Rays** or **Pith Rays** form radially arranged, light-colored streaks of various breadths which extend from the center, or other points, to the periphery and are especially noticeable under a lens. These also occur in coniferous woods, but are visible only after strong magnification (Fig. 116, *f*). In addition to annual rings and medullary rays we also find in oak wood small, mostly radial, but not regularly arranged or continuous, tail-like streaks consisting of **Wood Parenchyma**.

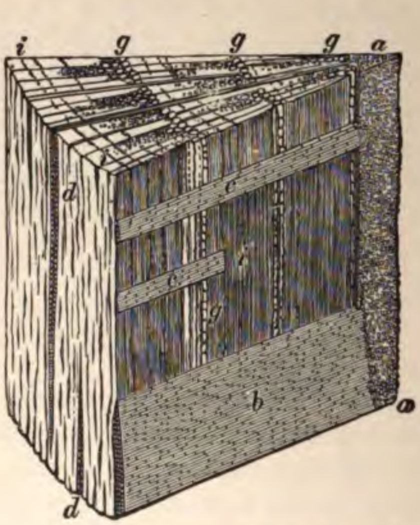


FIG. 115. Diagrammatic Representation of a Broad-leaved Wood. (TH. HARTIG.)
a pith; *b* and *c* medullary rays on the radial surface; *d* medullary rays on the tangential surface; *g* groups of vessels (pore rings); *i* summer wood; *aa* radial longitudinal section; *dd* tangential longitudinal section; *iai* cross-section.

In radial section we find streaks, parallel to the longitudinal axis of the stem, which obviously correspond to the annual rings seen in cross-section. Crossing these at right angles are the medullary rays, forming smooth, lustrous bands of different length and breadth (Fig. 115, *b*, *c*). Many of these, the so-called "primary rays", extend from the pith or medulla to the periphery, hence the name "medullary rays".

In tangential section the medullary rays are not, as a rule, visible to the naked eye, but on strong magnification their cross-sections appear as short pointed streaks distributed with little regularity among the other tissues (Fig. 117). The characteristic "grain" of wood is seen in tangential section, particularly in a large piece such as a board. This grain consists usually of ellipses, or hyperbolas, in the center, and open stripes at the sides. To understand this arrangement of the grain, the conical

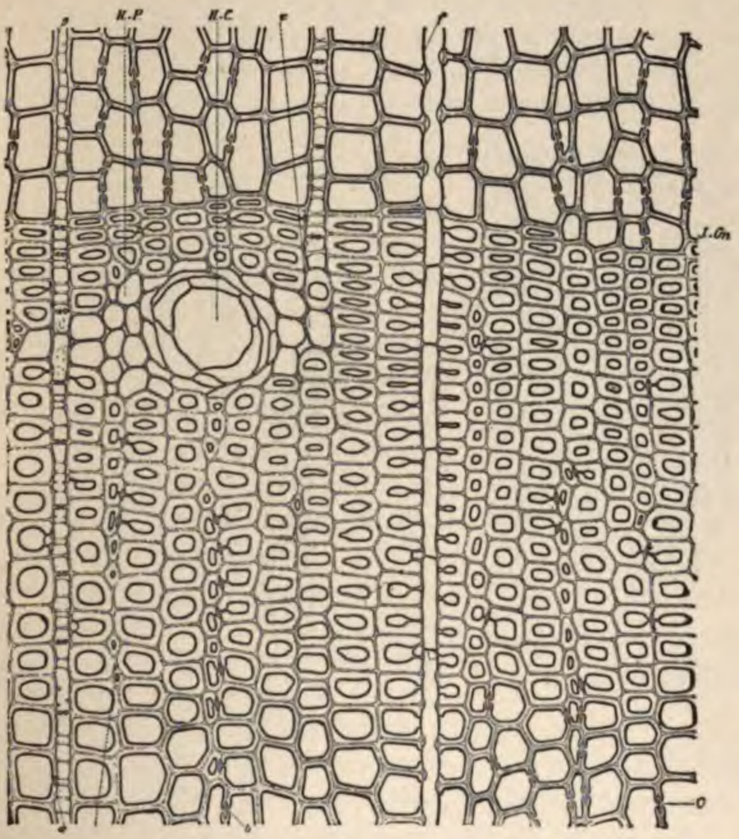


FIG. 116. Pine Wood in Cross-section. (KNY.)

f medullary rays; *g* cross-tracheids of the medullary rays; *HP* wood parenchyma about *HC* a resin canal; *o* and *c* bordered pits; *JGr* boundary of annual ring.

form of the trunk should be kept in mind, also the fact that the trunks of the coniferous and broad-leaved trees of the temperate zone increase in thickness during the growing season, while in the winter, the resting period, they do not grow at all. The conical trunk should therefore be regarded as made up of as many hollow cones as there are annual rings, the cones being nested one within another so as to form a compact whole. The part of each hollow cone formed in the summer is different from that formed in the spring both in anatomical structure and in physical properties, such as density, firmness, and color, and consequently is easily distinguished by the naked eye. It is therefore evident why these hollow cones in cross-section appear as rings (annual rings) and in radial section as stripes running nearly parallel to the axis of the trunk. In tangential section these zones of growth would be true hyperbolas or, at the sides, parts of hyperbolas; but, owing to the development of the branches, irregularities of growth, and other causes, the mathematical regularity is almost always destroyed, and the zones of growth commonly form, in tangential section, ellipses, wavy lines, and other figures, known as grain, which the grainer seeks to imitate with different shades of paint.

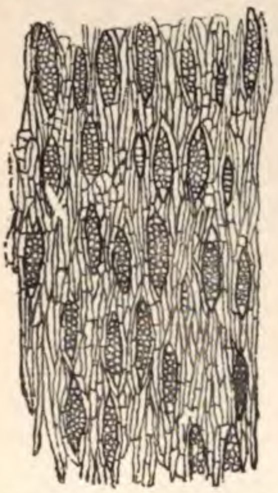


FIG. 117. Mahogany Wood in Tangential Section. (BECKER, from Reess' Botanik.)

The annual cone (annual ring) immediately adjoining the pith is designated the **Primary Wood**, the protoxylem or the protohadrome, to distinguish it from the succeeding layers forming the **Secondary Wood**. In roots the secondary wood, instead of forming continuous rings about the primary wood, is deposited between the plates of primary wood.

The medullary rays, as has been noted, are either evident to the naked eye, or else only after magnification with a lens, or, in the case of conifers, with a compound microscope. In many cases (e.g., white beech) the medullary rays are seen as individuals only under the microscope, but are situated close together so as to form compound or false rays clearly evident to the naked eye. Since the breadth of these false rays gradually diminishes until they are finally no longer visible to the naked eye, they are easily distinguished from true medullary rays.

CONIFEROUS WOODS.

Preparation of the material for examination is a simple matter. Transverse, radial-longitudinal, and tangential-longitudinal sections are cut either free-hand or with the aid of a hand section-cutter, taking care that resins, if present in considerable amount, are removed by placing the sections in strong alcohol. After treating with dilute potash solution and washing in water the sections are mounted in glycerine. With high powers

The primary membrane is common to two neighboring cells. On this are deposited the thickened layers, thus forming the secondary membrane which strengthens the wall and diminishes the size of the original lumen, while the primary wall is converted into the **Middle** or **Outer Lamella**. Since, however, the deposition of continuous thickened layers on all sides would prevent the translocation of the cell contents from one cell to another, the continuity of these layers is broken in numerous places, leaving the middle lamella as the only partition between the cell cavities. These places without thickenings, if very small, are known as **Pits** or **Pores**. We shall also see later that the arrangement may be reversed, the thickenings

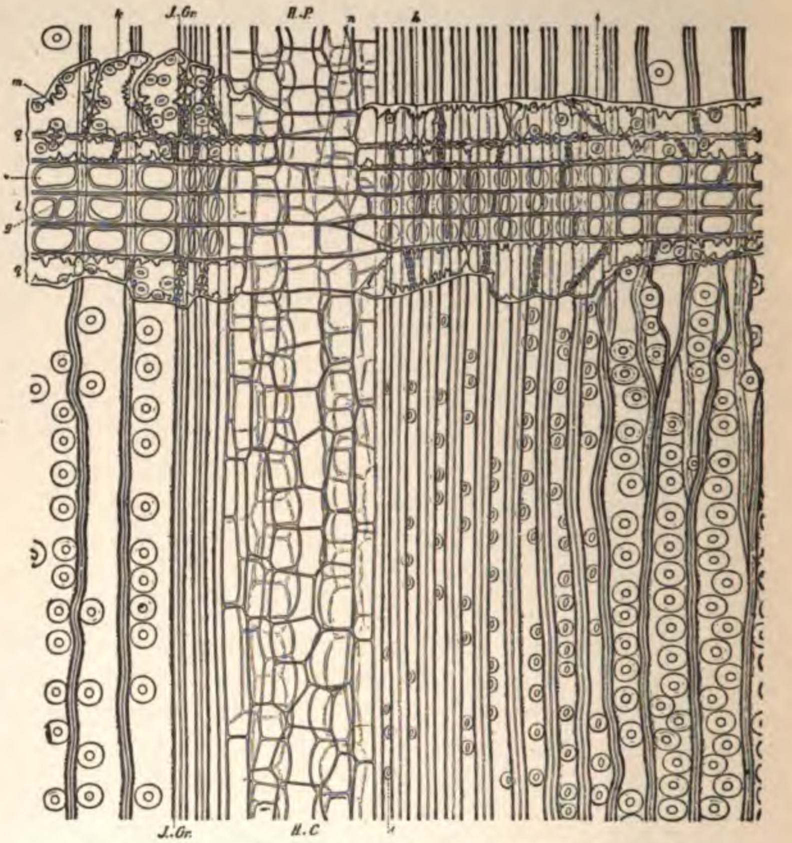


FIG. 118. Pine Wood in Radial Longitudinal Section. (KNY.)

l parenchyma cells and *q* cross-tracheids of the medullary rays; *HC* resin canal surrounded by *HP* wood parenchyma. The bordered pits of the tracheids are in surface view. *JGr* boundary of annual ring.

reduced to a relatively small surface, as is the case in annular and l vessels.

n order to form a bordered pit the secondary layers must be so de- ed as to leave a lens-shaped space (Fig. 120; 121, *A* and *B*) in the thickened wall, con- d with the lumen of each cell by a narrow which, in surface view, forms the small ring of the pit, while the outer boundary e lens-shaped cavity forms the larger outer (Fig. 121, *B*, left). DE BARY[1] aptly de- es a pit as a hole in the inner thickened s of a cell covered on the outer side by an ickened or only slightly thickened membrane. hole forms a canal which either is of uni- width (or narrowed slightly without), in h case it is known as a **Simple Pit**, or else is ptly enlarged toward the dividing membrane, forming a **Bordered Pit**. Corresponding to it in one cell is another in the adjoining cell, hat the covering membrane becomes the tion between the pits in the two walls. This brane, as shown by SANIO and RUSSOW, ins intact and, in fresh sapwood, is located e middle of the (double) pit cavity, but in the eartwood is usually pressed against one side e canal (Fig. 121, *A*, *a*, *t*). Another peculiar- f the covering membrane is the thickening or s (Fig. 121, *A*, *b*, *t*), which, as is often the in heartwood,[2] may close the pit like a . In the spring wood the torus is very thin; ummer wood, however, lens-shaped.[3] The lopment of bordered pits is evident from 121, *C*. Pits, as has been stated, permit location of material from one cell to another

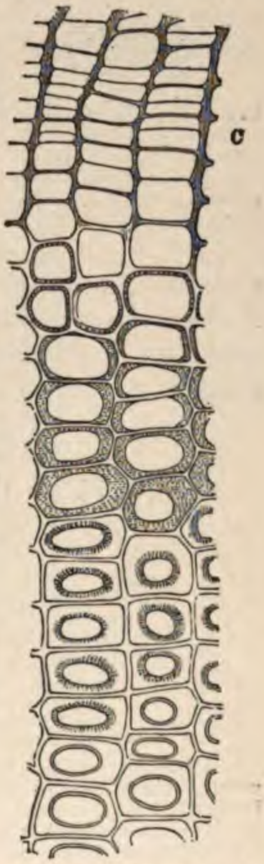


FIG. 119. Formation of Wood Elements in *Pinus*. (SANIO and v. TIEGHAM, from Reess' Botanik.)

C cambium layer from which are developed gradually the wood cells, with middle lamella and thickenings.

---

oc. cit., 165.

K. PAPPENHEIM: Zur Frage der Verschlussfähigkeit der Hoftüpfel im Splintholz der eren. Ber. Deutsch. Bot. Gesell. 1889, **7**, 2.

Russow: Bot. Centbl. 1883, **13**, 29.

without injuring at all the strength of the wall.[1] The liquors pass through the covering (separating) membrane by osmosis.

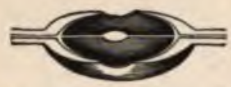


FIG. 120. Diagram of a Bordered Pit in Cross-section. (KERNER.)

The membrane with torus extends across the cavity of the pit.

The large bordered pits, mostly in a single row, furnish us with an admirable means for identification of coniferous woods, even in the smallest splinters. Attention has already been called to this character of coniferous woods in the chapter on the examination of paper (p. 117). It has also been noted that large bordered pits are not found on the sides of the fibers adjoining the cells of the medullary rays, but that the communication between the lumens of these two elements is through numerous small (simple or bordered) pits. A deeper layer of tracheids with large bordered pits may, however, in some cases be seen behind the medullary cells. But the radial walls of tracheids are not the only ones that are characterized by bordered pits. For example, the tangential walls of the wood cells of stone pine contain numerous bordered pits, although these are much smaller than the usual form (p. 188).

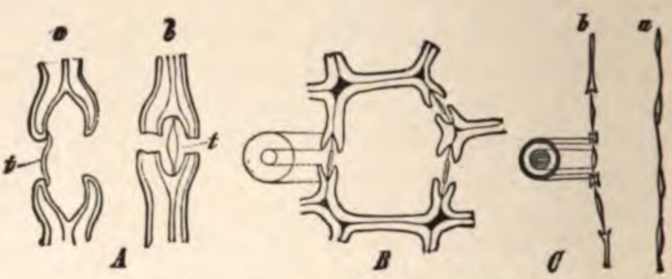


FIG. 121. Structure and Development of the Bordered Pits of *Pinus silvestris*. (RUSSOW and STRASBURGER, TSCHIRCH, from Reess' Botanik.)

A bordered pits as seen in tangential sections of the wood: *a* from air-dry summer wood; *b* from autumn wood; *t* torus. ×750.—*B* cross-section of a tracheid, showing bordered pits on the radial walls. ×400.—*C* development of bordered pits as seen in tangential sections: *a* early stage; *b* somewhat later stage, showing the beginning of the formation of pits and the thickenings of the walls. ×400.

The tracheids of the summer wood of many conifers (e.g., spruce, larch) display a system of parallel, alternately light and dark, diagonal striations. According to BURGERSTEIN,[2] these striations occur in the trunk wood of the spruce and larch or in the first annual rings. The same author states that these striations are in some cases parallel, either horizontally or diagonally, in other cases diagonally crossed or else spiral. Not infrequently it can be seen that the striations in the innermost annual rings are distinct, but in the succeeding rings become weaker and finally disappear.

---

[1] ZIMMERMANN: Die Morphologie und Physiologie der Pflanzenzelle. Breslau, 1887, 141.

[2] Vergleichend-anatomische Untersuchungen des Fichten- und Lärchenholzes, 17.

The elements of yew wood (*Taxus baccata* L.) have, in addition to bordered pits, thickenings in the form of spiral bands (Fig. 122), which are obviously of great diagnostic value.

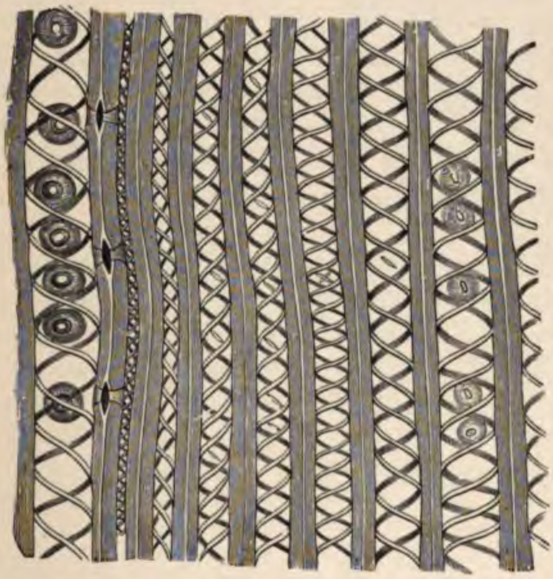


FIG. 122. Wood of *Taxus baccata* in Radial Section, Showing Pits and Spiral Bands. (G. A. WEISS.)

Extending into, or bridging over, the lumens of the tracheids of certain conifers are bar-like ingrowths (Fig. 128, *b*) of the cell wall, to which C. MÜLLER, in honor of their discoverer, has given the name **Sanio Bars**. C. MÜLLER [1] has found these bars in numerous coniferous woods and concludes that they are a characteristic of all conifers and are not anomalous or pathological formations; furthermore, that they occur in all the axial organs of stems, branches, and roots, at all heights and in all parts and in the youngest and oldest rings.

---

[1] Ueber die Balken in den Holzelementen der Coniferen. Ber. Deutsch. Bot. Gesell. 1890, 8, Generalversammlungsheft 17. The article also contains a bibliography of Sanio bars and an account of their morphology and mechanical significance.

We have seen that the distinction between the tracheids of spring and summer wood lies in the difference in both the size of the lumen and the thickness of the walls. It will be of interest to the technical microscopist to learn the theories which have been advanced by investigators as to the cause of this different development and its periodicity. Some have attributed the spring and summer wood to an especial need of water channels in the spring and of mechanical support in the autumn; others have believed the phenomena to be due to the unfolding of the buds in the spring and to the closing of the same in the autumn, or to good and poor nutrition, or to hereditary peculiarities. The theory has also been advanced that the chief cause of the formation of spring and summer wood is the difference in water content in the bark and the region of the young wood.[1]

Medullary Rays.—The cells forming the medullary rays constitute the second tissue element of coniferous woods.[2] As we have learned from the general outline of the structure of wood, the medullary rays take up a relatively small space and are not evident to the naked eye in cross-section, but are visible in radial section as shining streaks. Those rays which extend from the pith to the periphery are called *primary;* those which spring from any of the annual rings are called *secondary.*[3] In each medullary ray we distinguish the height and the breadth, both of which are dependent on the number of cells. Cross-sections of the stem show the medullary rays in longitudinal view from above or below, and radial sections show them in longitudinal view from the side; on the other hand, tangential sections alone give an idea of the size of the medullary rays, since in these sections we see their height and breadth, or, in other words, we view them in cross-section. From this it is clear that a study of medullary rays brings out the importance of sections cut in the three directions.

---

[1] K. G. Lutz: Beiträge zur Physiologie der Holzgewächse. Ber. Deutsch. Bot Gesell. 1895, **13**, 185.

[2] See also Essner: Ueber den diagnostischen Werth der Anzahl und Höhe der Markstrahlen der Coniferen. Halle, 1882. A. Kleeberg: Die Markstrahlen der Coniferen. Bot. Ztg. 1885, **43**.

[3] Of especial interest is the manner in which the primary and secondary medullary rays originate respectively in the pith and in the tracheid tissue. According to the investigations of Kny (Botanische Wandtafeln mit erläuterndem Text. 6. Liefg. 1884, Text, 221) and Erich Schmidt (Ein Beitrag zur Kenntniss der secundären Markstrahlen. Ber. Deutsch. Bot. Gesell. 1889, **7**, 143), each medullary ray of ***Pinus silvestris*** starts with two rows of initial cells which, like the parenchyma cells of the pith from which they spring, are very simple in structure but show a marked elongation in a horizontal direction. The connection between pith and medullary ray is often by a single medullary cell, but, as noted by Schmidt, in some cases is by three or more parenchyma cells pushed out from the pith between the wood cells, thus forming several courses. Each secondary medullary ray starts in the boundary between the tracheid zone of the last spring and that of the following autumn, in such a manner that the first cell of the medullary ray is pushed between two tracheids, arranged in the same longitudinal direction, cutting off the lower one with a horizontal cross-wall. The longitudinal tracheid behind the medullary cell is also cut off by a cross-wall which lies at the height of the upper elongated (horizontal) wall of the medullary cell. It thus appears that the formation of truncated ends on tracheids is associated with the insertion of the medullary rays.

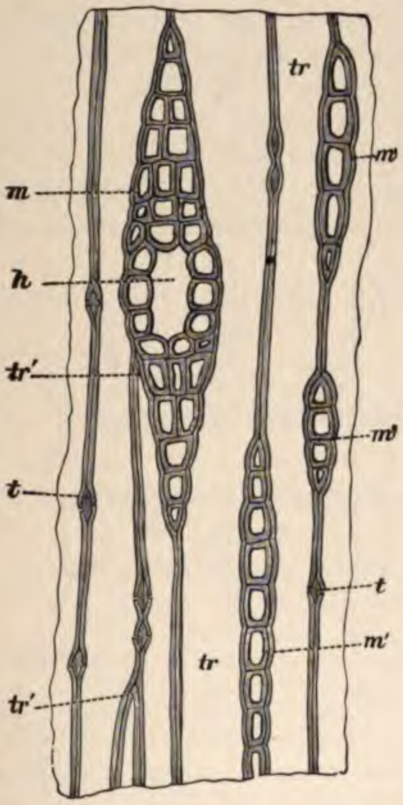


Fig. 123. Spruce Wood in Tangential Section. (T. F. Hanausek.)

m medullary ray with several layers of cells and *h* a resin passage; *m'* medullary ray with single layer of cells of different height; *tr* tracheids; *t* sections of bordered pits; *tr'* ends of tracheids.

Most coniferous woods have one-rowed medullary rays, that is, they consist of a single layer of cells arranged one above the other between the tracheids (Fig. 123, *m'*). The medullary rays in many kinds of woods have intercellular spaces filled with resin (Fig. 123, *h*), and in such cases there are several rows of cells in each ray.

While the tracheids in the different coniferous woods have generally the same structure and therefore, with few exceptions, are of little value in diagnosis—for example, spruce and fir cannot be distinguished by the tracheids—on the other hand, the medullary rays are of great valu to the technical microscopist, since by their characteristic and specif structure he can distinguish the coniferous woods of greatest econo importance, namely, spruce, fir, and pine.

THE MEDULLARY RAYS OF FIR WOOD are in one layer, the cells, of which are of the same kind, being elongated, with diagonal or perpe dicular cross-walls and rather numerous simple pits. In radial sectio long portions of the side walls are often without pores, while the end wal

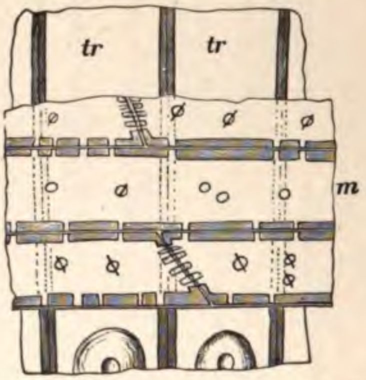


FIG. 124. Part of Medullary Ray of Fir Wood in Radial Section. (T. F. HANAUSEK.) *m* medullary cells; *tr* tracheids.

on the other hand, commonly contain so many pores that the thickenings appear like narrow transverse bars (Fig. 124). The pits in surface view are circular and often are crossed by a streak which passes through the center and extends beyond the periphery—a phenomenon explained in the foot-note, p. 291.

THE MEDULLARY RAYS OF SPRUCE WOOD are for the most part in one layer; only in cases where a resin cavity is present are they in several layers. Two kinds of cells are present: (1) the edge cells, that is, those on the upper and under edge, known as **Cross-tracheids**, have diagonal cross-walls and bordered pits (Fig. 125, *ä.m.*); (2) the inner cells, known as **Conducting Cells**, since they serve to conduct and store up nutritive matter,[1] are more strongly thickened and have simple pits (Fig. 125, *i.m.*). The bordered pits are usually very distinct in sections of the diagonal end walls of the cross-tracheids: if the knife passed through the diameter of a pit the canal is evident; if this was not the case the pit appears elliptical or digonous.

---

[1] BURGERSTEIN: *loc. cit.*, 20.

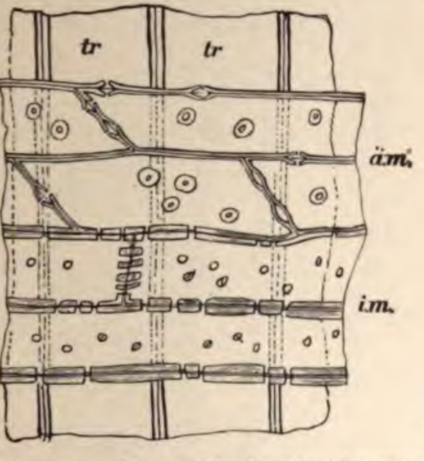


FIG. 125. Part of Medullary Ray of Spruce Wood in Radial Section. (T. F. HANAUSEK.) *ä.m* outer medullary cells (cross-tracheids); *i.m* inner (conducting) medullary cells; *tr* longitudinal tracheids.

THE MEDULLARY RAYS OF PINE WOOD[1] are also made up of two kinds of cells. Typical forms of these cells are found in the wood of the Scotch pine (*Pinus silvestris* L.) and the black pine (*P. nigra* Arnold). The edge cells are cross-tracheids with very irregularly developed second-

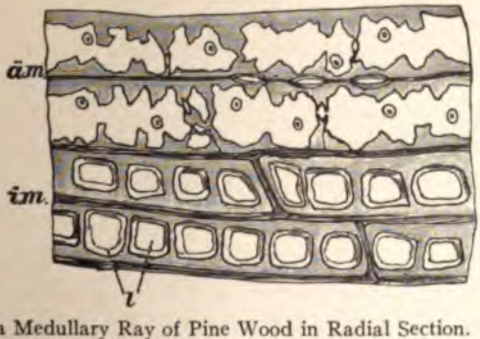


FIG. 126. Part of a Medullary Ray of Pine Wood in Radial Section. (T. F. HANAUSEK.) *ä.m* outer medullary cells; *i.m* inner (conducting) medullary cells; *l* open pits.

---

[1] KNY: Anatomie des Holzes von *Pinus silvestris*. Berlin, 1884.

ary thickening, giving the lumen a zigzag outline (Fig. 126, *ä.m.*; Fig. 118). Bordered pits occur in considerable numbers. In the Scotch pine commonly two, less often three, rows of these zigzag cells occur in each of the edges (the upper and lower ends as seen in tangential section) of the ray. The inner cells (conducting cells) have large, roundish or rounded quadratic open pits, which might be mistaken by the beginner for isodiametric parenchyma cells, although on careful examination he would soon find the true cross-walls of the elongated medullary parenchyma cells. The medullary rays of the black pine are made up of cells having the same structure, but I find that the zigzag cells form 4–6 rows, and that very often a row of these cells is inserted between the cells with open pits.

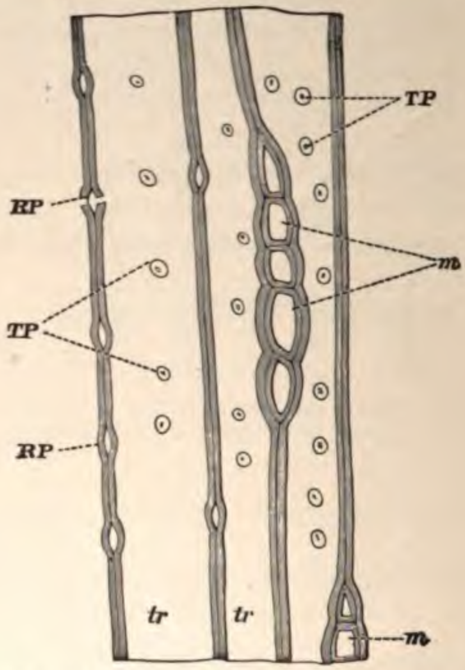


FIG. 127. Cembra Wood (*Pinus Cembra*) in Tangential Section. (T. F. HANAUSEK.) *m* medullary rays; *tr* tracheids; *RP* large bordered pits on the radial walls of the tracheids, in cross-section; *TP* small bordered pits on the tangential walls of the tracheids.

All species of the genus *Pinus*, however, do not have medullary rays of the above type. In the white pine (*P. strobus* L.) and the stone pine (*P. Cembra* L.) the zigzag thickenings of the outer cells are absent or only occasionally present. These outer cells in the stone pine, like those of the spruce, have small bordered pits, and the thickening on the side walls is comparatively thin, with here and there a projecting tooth. The conducting cells have the typical open pits. Another very remarkable peculiarity is the presence of small bordered pits (Fig. 127, *TP*) on the tangential walls of the tracheids occurring in the vicinity of the medullary rays. These pits occur scattered over the surface and, on careful examination, may also be seen in radial section. KRAUS[1] finds these tangential pits also in larch and spruce.

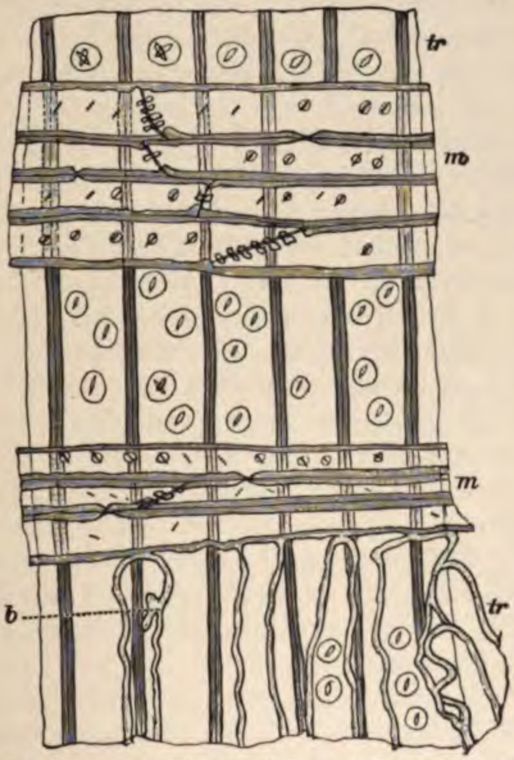


FIG. 128. Red Cedar (*Juniperus Virginiana*) in Radial Section. (T. F. HANAUSEK.) *m* medullary rays; *tr* (above) tracheids; *tr* (below) tracheids beginning at medullary rays with *b* Sanio bars (p. 183).

THE MEDULLARY RAYS OF RED CEDAR (*Juniperus Virginiana* L.) are of a less distinctly marked type. They are mostly provided with bordered pits, but the borders are so delicate and faintly marked that they can be found only after very careful observation. The cross-walls are diagonal, with broad pits often of such a size that only a single narrow thickening occurs in the center of the wall (Fig. 128, the middle cells of the upper medullary ray); pits also occur in an angular projection of the longitudinal wall. Along the edges of the rays occur tracheids (*tr*) with rounded ends and irregular, often crooked, course. These also occur in spruce (see Fig. 118, below the medullary ray on the right). Not infrequently Sanio bars (p. 183) can be seen in these tracheids (Fig. 128, *b*).

---

[1] KRAUS, GREGOR: Mikroskopische Untersuchungen über den Bau lebender und vorweltlicher Nadelhölzer. Würzburger Naturw. Ztschr., **5**, 156. Cited on the authority of A. BURGERSTEIN.

THE MEDULLARY RAYS OF LARCH are very much like those of spruce. Characteristic is the strikingly rich deposit of resin in the conducting cells. While the differences in the medullary rays of fir, pine, and spruce, as we have seen, enable us readily to distinguish these woods, it is exceedingly difficult to distinguish spruce and larch by their microscopic characters. Large pieces of sound wood are readily distinguished by the characters noted in the analytical key on p. 216, but if the wood is decayed or in small splinters, a detailed investigation is necessary.[1] A. BURGERSTEIN[2] has summarized those characters of the trunk, root, and branches which are of value in distinguishing spruce from larch, as follows:

"The histological elements of the root, trunk, and branches of larch are thicker and stronger than those of spruce. The wood cells of larch are longer, broader, and thicker-walled; the pits are larger, and much oftener developed in two rows on the radial walls of the spring tracheids than in spruce. The medullary rays of larch, in respect to the number of cells, are more extensive; the conducting cells are higher, broader, and possibly also longer; usually they are resinous. Following are the principal distinctions of trunk, branch, and root:

"In spruce the spring tracheids of trunk and root have nearly the same-sized lumen, commonly $30–40\mu$. In the first-formed annual rings of the trunk the wood cells are narrower than in the later annual layers, which is not true of the root. The diameter of the spring tracheids in the branches is markedly smaller, usually only $15–20\mu$.

"The spring tracheids in both the trunk and root of the larch have lumens with nearly the same radial diameter. The commonest size is $40–60\mu$. As in spruce, the narrowest wood cells of the trunk are in the spring wood, which is not the case in the root. In the branches the diameter of the spring tracheids is mostly only $20–30\mu$.

---

[1] A striking example is the "Stock im Eisen", a notable landmark of the city of Vienna, which Professor UNGER in 1856 pronounced as probably the remains of a larch. A. BURGERSTEIN (Der Stock im Eisen. Wien, 1893) has shown that it is the remains of a spruce.

[2] Vergleichend-anatomische Untersuchungen des Fichten- und Lärchenholzes, 39.

"The diameter of the outer cavity (outer circle) of the pits in the trunk and root wood of spruce (excepting the first annual rings of the trunk) is usually greater than 18μ, while in the branch wood it is never greater than this figure. In the branch wood of the larch, the diameter of the outer cavity of the radial pits varies up to about 25μ, whereas in the trunk and root wood it varies up to 30μ; the minimum diameter in trunk and branch wood is 15μ, whereas in root wood it is not below 20μ.

"Twin pits do not occur in the branch wood of spruce and larch, but are present, as a rule, in the root wood of spruce, and almost always, although in variable numbers, in the root wood of larch. While in the trunk wood the double rows of pits increase in number from year to year—in the first five annual rings they are always absent—in the root wood, on the other hand, twin-pits are always found in the inner wood layers and more commonly diminish in number in the annual rings of succeeding years.

"The height of the (conducting) cells of the medullary rays, from the trunk and branch wood, aside from those in the first annual rings of the trunk, is about the same in spruce (17–20μ) and larch (20–22μ). In the root wood the cells are higher, namely (excluding extremes) in spruce 20–25μ and in larch 24–30μ. Frequently the conducting cells of the root wood are filled with starch.

"The average height of the medullary rays of spruce and larch, measured in number of cells, is greatest in the trunk, less in the root, and least in the branches. As a rule the height of the medullary rays is less in spruce than in larch, the maximum height in both conifers being 20 cells in the branches, 30 in the roots, and 40 in the trunk.

"Medullary rays, partially with two layers, occur here and there throughout.

"Resinified conducting cells seldom occur in the medullary rays of spruce, but are the common form in larch; there are, however, exceptions to these rules.

SCHRÖDER'S MEDULLARY COEFFICIENT[1] is of service in diagnosis only after making a great number of determinations (about 100 for a medullary ray of a certain height).

---

[1] SCHRÖDER (Das Holz der Coniferen. Dresden, 1872) used this term for the ratio of the number of conducting cells to the number of cross-tracheids. If we count the number of both kinds of cells in a considerable number of medullary rays, each consisting of five rows, one above the other, and divide the average number of conducting cells (J) by the average number of cross-tracheids (A), we obtain the medullary coefficient (C) of the medullary ray of the height (S). Then $C=J:A$ and $S=J+A$.

"Larch wood is one of the vegetable materials in which manganese has been found."

A summary of the diagnostic characters of larch and spruce woods follows:

BURGERSTEIN'S ANALYTICAL KEY FOR SPRUCE AND LARCH WOODS.

I. Twin pits not present.

A. Spring tracheids 20–40μ. Average height of medullary rays, 7-11 cells.
  (*a*) Cells of medullary rays 17–20μ high. Medullary rays of one layer and 10 cells high form about 20 per cent of the whole number; seldom resinified..................Trunk wood of Spruce.
  (*b*) Cells of medullary rays, 20–40μ.
    * Diameter of outer circle of pits mostly 21–26μ. Maximum height of medullary rays 30 cells; mostly not resinified..................................Root wood of Spruce.
    ** Diameter of outer circle of pits mostly 14–22μ. (Medullary rays mostly resinified).
    Trunk wood of Larch (inner annual rings).

B. Spring tracheids 15–30μ. Average height of medullary rays 4.5-7 cells; maximum height 20 cells.
  (*a*) Spring tracheids 15–20μ; diameter of outer circle of pits 14–17μ (never over 18μ). Summer tracheids striated.
  Branch wood of Spruce.
  (*b*) Spring tracheids 20–30μ; diameter of outer circle of pits 16–24μ. Summer tracheids striated or not striated..Branch wood of Larch.

II. Twin pits present.

A. Spring tracheids 30–40μ. (Medullary rays seldom resinified.)
  (*a*) Cells of medullary rays 17–20μ high. Diameter of outer circle of pits also under 19μ. Twin pits mostly occur singly distributed between simple pits, seldom one above the other in several rows.
  Trunk wood of Spruce.
  (*b*) Cells of medullary rays 20–26μ high; conducting cells often containing starch. Diameter of outer circle of pits not under 19μ; double pits occur singly or in several rows one above the other or wholly covering the spring tracheids. Summer tracheids, in exceptional cases, striated............Root wood of Spruce.

B. Spring tracheids 40–60μ. Medullary rays very frequently resinified.

(*a*) Cells of medullary rays 20–23μ high. Average height of medullary rays 9–13 cells; maximum height 40–50 cells. The single-layered medullary rays, more than 10 cells high, form about 38 per cent of the whole number. Diameter of outer circle of pits also under 20μ........................Trunk of wood Larch.

(*b*) Cells of medullary rays 24–30μ. Average height of medullary rays 7–9 cells; maximum height 30 cells. Summer tracheids in exceptional cases striated. Diameter of outer circle of pits not less than 20μ........................Root wood of Larch.

NOTE.—The figures given for the spring tracheids are the radial diameters. The pits referred to are those on the radial walls of the spring tracheids. All figures for height of medullary cells refer to the conducting cells (with simple pits). Figures for height of medullary rays include in each case both conducting cells and cross-tracheids.

Wood Parenchyma.—The third tissue element of coniferous wood is the so-called wood parenchyma. Although this tissue is extensively developed in many broad-leaved woods, in coniferous woods it is present in such small amount that it may be spoken of as an occasional constituent. Only where resin canals occur in the tracheid tissue do we find long rows of parenchyma cells (Fig. 118, *HP*). Yew wood (*Taxus baccata*) is entirely free from this tissue.

It may here be stated that in the first year's wood of the conifers, the so-called medullary sheath, occur tracheids with spiral or annular thickenings which also are found in other parts of the plant, as, for example, in the scales of the cones. These tracheids, formerly regarded as vessels, are of very little importance to the technical microscopist.

On the other hand, we must consider briefly the resin passages, to which reference has been made repeatedly, since these play an important rôle in many vegetable parts used for technical purposes. In this connection the resin cavities of other plants should be considered, disregarding, however, secretion cells and latex tubes.

Excretion or Secretion Cavities of plants may be formed in two ways. Commonly they are intercellular cavities[1] which are wholly or partly filled with the excretion product, which may be resin, essential oil, gum, or a mixture of these substances. Very often the resin chamber is formed by the splitting apart of cells originally united, in which case it is known as a **Schizogenous** excretion (or secretion) cavity. In other cases the chamber owes its origin to the disorganization, solution, or even rupture of definite cells, and is for this reason known as a **Lysigenous** cavity. The cells surrounding the schizogenous cavity generally have the characters of parenchyma cells (see Fig. 118). Whenever their form is essentially different from that of the neighboring parenchyma cells, they form a true lining or epithelium of the intercellular space which may have one or more cell layers.

---

[1] FRANK: Beiträge zur Pflanzenphysiologie. Leipzig, 1868, Table 3, Figs. 11 and 12. T. F. HANAUSEK: Ueber die Harzgänge in den Zapfenschuppen einiger Coniferen. Krems, 1879 and 1880. V. HÖHNEL: Anatomische Untersuchung über einige Secretionsorgane der Pflanzen. Sitzb. Wien. Akad. Wiss. 1881, 565. N. J. C. MÜLLER: Untersuchung über die Vertheilung der Harze, äth. Oele etc. und die Stellung der Secretbehälter im Pflanzenkörper

Fig. 129 shows large schizogenous cavities (*oe*), each surrounded by an epithelium, the cells of which are tangentially elongated and are much smaller than the other parenchyma cells. Cross-sections of an orange leaf (Fig. 130) and of the wood of *Copaifera Langsdorffii* (Fig. 131) show how lysigenous cavities are formed by the solution of the cells. **Sohizolysigenous** canals result from a combination of both processes, the cavity being first formed by the splitting apart of the cells, after which it is enlarged by the absorption of the surrounding cells. The author demonstrated in the year 1878 that the cavities in the fruit of *Myrospermum frutescens* Jacq.[1] are due to a combination of both methods of formation, which Frank and also Thomas had previously found was true of the resin cavities of the pine. The mesocarp of the fruit named contains, in addition to numerous small balsam reservoirs, a larger reservoir which probably was formed schizogenously and was enlarged by the resinification of the adjoining cells.

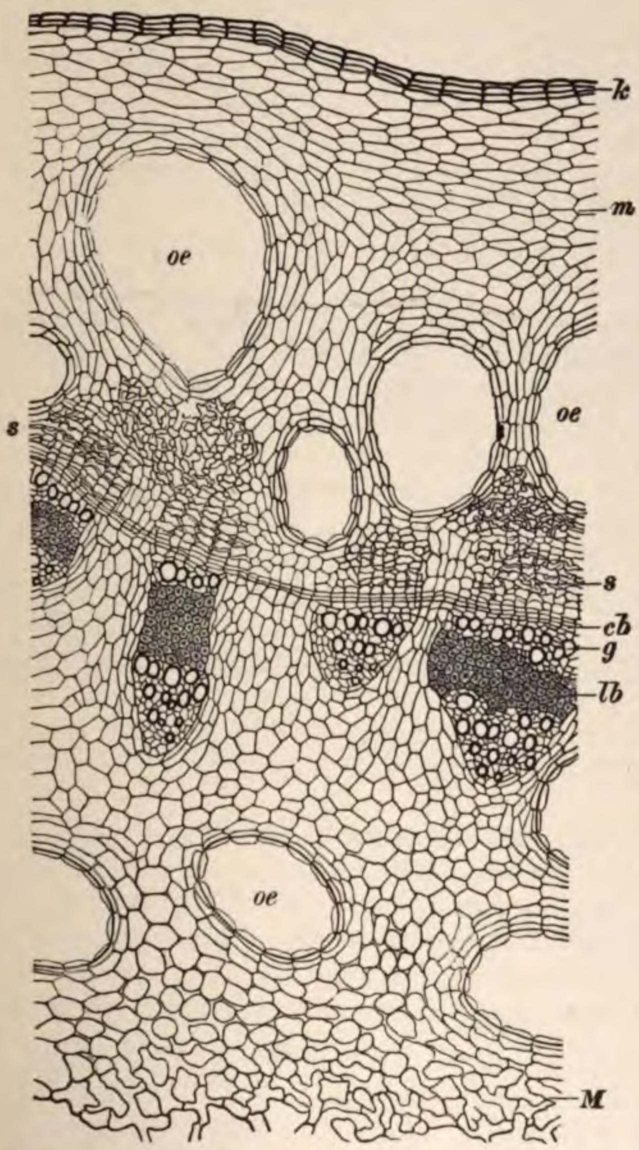
As to the origin of the secretion, formerly it was held that in the case of schizogenous intercellular spaces the secretion was derived from the contents of the surrounding cells, while in the case of lysigenous cavities it appeared in the protoplasm of the cells in the form of small drops, which rapidly increased in size and number and, after the walls had disappeared, flowed together, forming a large mass.[2] According to

---

Pringsheim's Jahrb. Wiss. Bot., **5**, 387. Tschirch: Angew. Pflanzenanat., 485. *Idem:* Die Harze, etc. Leipzig, 2. Aufl. 1906. Wiesner: Rohstoffe. 2. Aufl. 1900, 145.

[1] T. F. Hanausek: Zur Anatomie der Frucht von *Myrospermum frutescens* Jacq. und deren Balsambehälter. Ztschr. allg. Österr. Apoth. Ver. 1878, **16**, 376.

[2] De Bary: *loc. cit.*, 214. A. Tschirch: Ueber die Entwicklungsgeschichte einiger Secretbehälter und die Genesis ihrer Secrete. Ber. Deutsch. Bot. Gesell. 1888, **6**. This old theory, however, has recently been defended by Schwabach (Ber. Deutsch. Bot. Gesell. 1899, **31**, 291), who states that in *Abies* and *Pinus* the resin is formed in the cells surrounding the cavity, while in *Picea*, in conformity to Tschirch's theory, it has its origin in the membrane. R. Müller (Deutsch. Bot. Gesell. 1906) also disputes Tschirch's theory.



129. Cross-section through the Periphery of the Rhizome of *Imperatoria*. (Tschirch.)
cork; *m* primary bark; *oe* schizogenous oil passages; *s* sieve bundles; *cb* cambium;
els; *lb* libriform fibers (wood fibers); *M* pith.

TSCHIRCH,[1] the secretion of schizogenous cavities is not formed in this way. "Contrary to the formerly accepted view that the essential oil appears in the cells surrounding the cavity and from these is removed to the cavity itself, it has been shown that the schizogenous epithelium is entirely free from secretion and serves merely to confine the resinous substance to the canal. The formation of resin really takes place in the strongly swollen cell wall of the secreting cells adjoining the canal." This swollen wall is a mucilaginous membrane separated from the canal by a delicate inner skin[2] which is unacted on by sulphuric acid and Schultze's mixture. Since the resin is formed at the expense of the wall itself, as it increases in amount, the membrane diminishes in thickness.

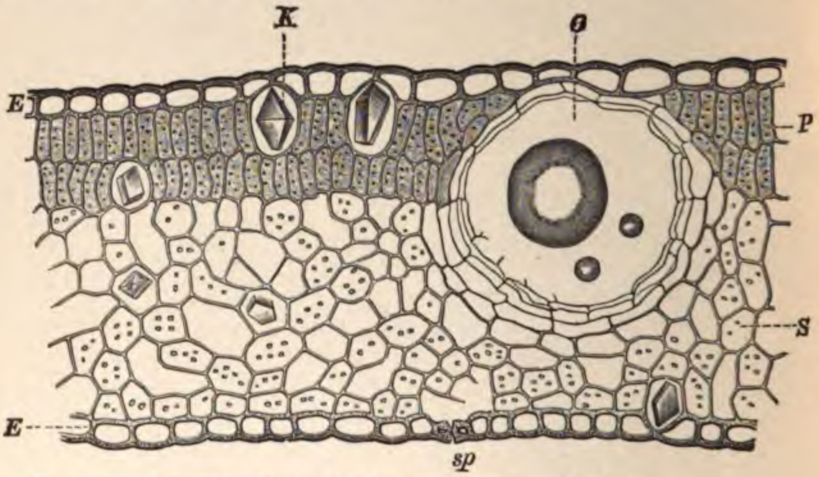


FIG. 130. Orange Leaf in Cross-section. (TSCHIRCH.)

O lysigenous oil cavity; *E* epidermis; *sp* stoma; *P* palisade parenchyma; *S* spongy parenchyma; *K* crystal.

BROAD-LEAVED WOODS OF THE TEMPERATE ZONE.

The histological elements of broad-leaved woods are (1) **True Wood Fibers** (libriform fibers, sclerenchyma fibers), (2) **Vessels** or **Tracheæ**, (3) vessel-like wood cells or **Tracheids**, (4) **Wood Parenchyma**, and (5) cells of the **Medullary Rays**. The cells, known by SANIO as substitute fibers, constitute a special class. The proportion of these elements varies greatly according to the species; in general, however, it may be said that the tracheal forms predominate in spring wood, the purely mechanical forms, such as wood fibers, in summer wood.

---

[1] Ueber die Bildung von Harzen und ätherischen Oelen im Pflanzenkörper. Pringsheim's Jahrb. Wiss. Bot. 1893. Heft 3, **25**.

[2] TSCHIRCH: Ueber den Ort der Oel- bezw. Harzbildung bei den schizogenen Secretbehältern. Ber. Deutsch. Bot. Gesell. 1893, **11**, 201.

As a typical example we will select the red beech (*Fagus silvatica*), the elements of which are shown in Fig. 132.

The **Libriform Cells**[1] are mostly elongated, more or less strongly thickened, and strongly lignified fiber cells (Fig. 132, *e*, *f*, *g*, *h*), which are nearly free from pores except for simple, mostly diagonal cleft-pores found on the radial walls. In cross-section (Fig. 138) they are either rounded or polygonal and often display a gelatinous inner layer or tertiary membrane. Sometimes the fibers have knotty outgrowths or branches or else are forked at the ends. There is no sweeping distinction between libriform fibers and the bast fibers described in the chapter on vegetable

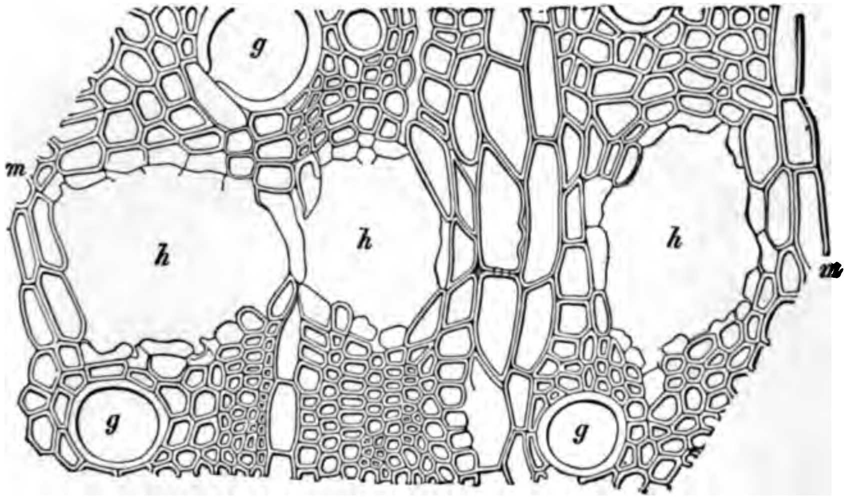


FIG. 131. Small Lysigenous Resin Passages (*h*) in Wood of *Copaifera Langsdorffii* after Removal of Secretion with Alcohol. (TSCHIRCH.)
m medullary rays; *g* vessels.

---

[1] DE BARY: *loc. cit.*, 496. TSCHIRCH: Angewandte Pflanzenanatomie, 297. The following references apply to this and the subsequent sections: HARTIG: Forstliche Culturpflanzen. Berlin, 1851. MOELLER: Das Holz. Cassel, 1883. *Idem:* Beiträge zur vergleichenden Anatomie des Holzes. Denkschr. Math. Naturw. Cl. d. Wien. Akad. 1876, **36**. SANIO: Ueber die Zusammensetzung des Holzkörpers, etc. Bot. Ztg. 1863, 401. SOLEREDER: Holzstructur. München, 1885. *Idem:* Systematische Anatomie der Dicotyledonen Stuttgart, 1898–1899. WIELER: Anatomie und Ausbildung von Libriformfasern in Abh. v äuss. Verh. Bot. Ztg. 1889, 517.

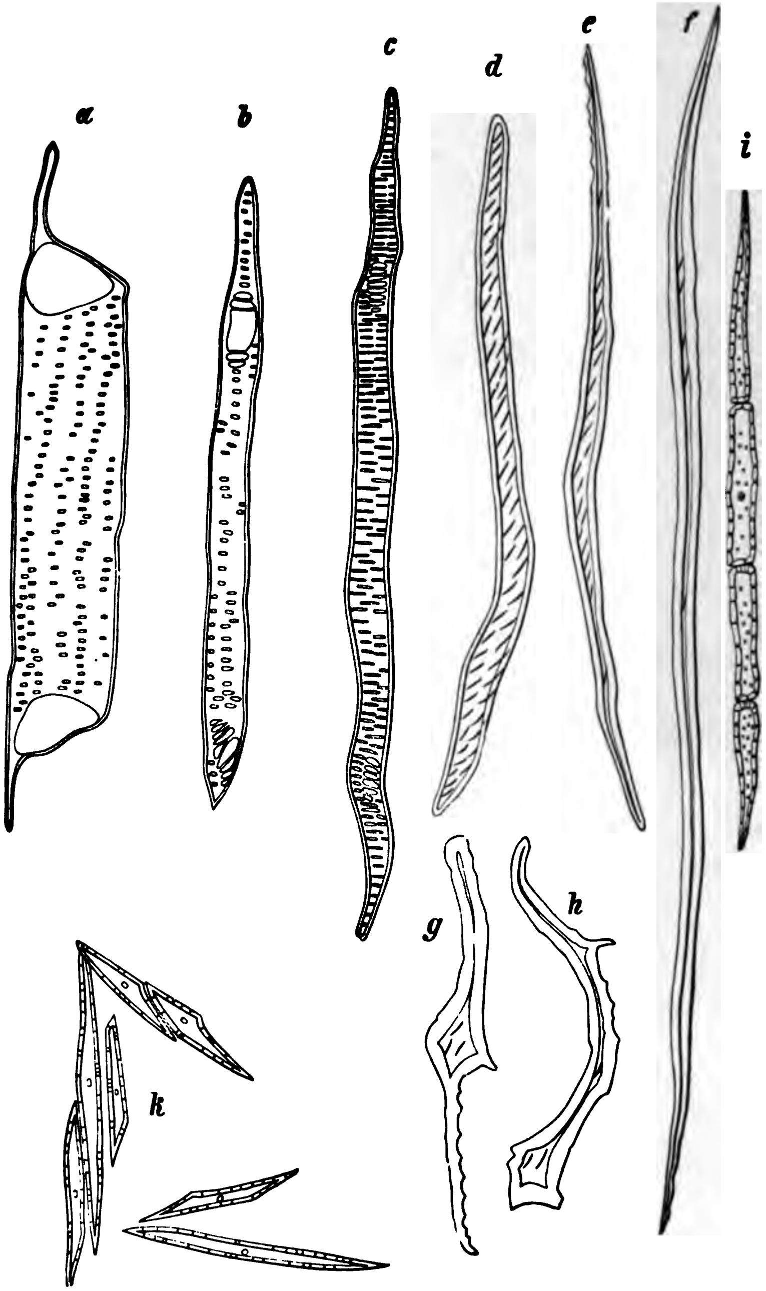


FIG. 132. Isolated Elements from Old Wood of Red Beech (*Fagus silvatica*). (SCHWARZ, from Reess' Botanik.)

a and *b* vessels; *c* and *d* tracheids; *e–h* libriform cells (true wood fibers); *i* wood parenchyma; *k* medullary cells.

ibers. This similarity is not surprising, since both are mechanical ele-
nents serving much the same purpose. In most economic broad-leaved
voods these libriform cells play the chief rôle.

Libriform fibers are isolated by boiling very thin splinters of the wood
n Schultze's macerating mixture (nitric acid and potassium chlorate)
nd, after washing in water, gently rubbing. Isolated wood elements
nay also be conveniently obtained from paper stock made from wood
ulp.

Vessels or **Tracheæ** are simple or jointed tubes, formed from several
r many cells arranged end to end in rows by the more or less complete
eabsorption of their cross-walls. A never-lacking characteristic is the
eculiar thickening of the walls. TSCHIRCH states that the reabsorption of
he cross-walls of the original cells takes place after the thickening of the
valls, and that the boundaries of the individual cells are evident as joints
ven after the union is complete. Vessels in cross-section usually appear
s more or less circular holes, easily distinguished from the lumens of
djacent cells by their greater size. The diameter of the vessels in the
vood of a given species varies according as they occur in the spring or
ummer wood, being almost always less in the latter than in the former.
n addition to the distribution of the vessels, which will be considered
detail later, the different forms of thickenings of the walls are of special
nportance. According to the nature of the thickening, vessels are
esignated annular, spiral, reticulated, or pitted (Fig. 133, *b*, *c*, *d*, *g*).
nnular Vessels are characterized by the ring-shaped thickenings. They
cur chiefly in the monocotyledons (see Straw Paper Stock, p. 110,
ig. 85, *r*, and Fig. 87, *rg*). **Spiral Vessels**, that is vessels with cork-
rew-like thickenings, are found in great numbers in many plants.
itted Vessels are of two kinds: (1) those with simple pits or pores; (2)
ose with bordered pits (p. 179, Figs. 120 and 121). Bordered pits often
ccur in such large numbers on the walls of the vessels that they are
attened on opposite sides, and as a consequence their contour is sharply
olygonal (Fig. 180). The ends of the vessels are difficult to find, although
e task is greatly facilitated by isolating the elements. Often we note
eculiar tail-like outgrowths which doubtless were derived from the
riginal cells. The union of one vessel with another is of common occur-
ence, and not infrequently the place of juncture shows scalariform per-
orations.

It may be well to state that the distinction between vessels and tra-
heids lies chiefly in the method of formation. A tracheid is a cell, a

vessel, a cell fusion. If the cross walls separating the original cells remain intact, the characters of the vessel are less strongly pronounced, and in such cases, as noted by TSCHIRCH,[1] we should not speak of vessels, but of vessel-like tracheids arranged end to end in rows.

We find in many woods vessels stopped up with a peculiar filling-tissue, the cells of which are known as **Tyloses.**[2] Since these occur in numerous technical woods (oak, sycamore, locust, elder, grape, fustic), it is necessary that we understand their structure and development. Tyloses form in the vessels bladdery, wrinkled, less often regularly formed, cell formations which, as was first shown by BÖHM, serve to stop up the vessels so that they cannot conduct water, but may also serve, like wood parenchyma, as storing organs for starch. They occur in spiral, annular, and pitted vessels. In many woods (e.g., snake-wood) tyloses are converted into true stone cells by the thickening of the cell walls.

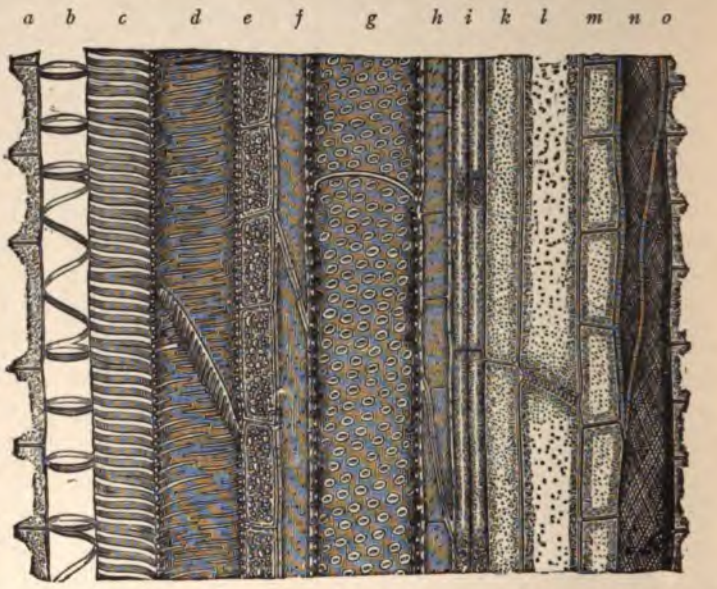


FIG. 133. Longitudinal Section through an Ideal Dicotyledonous Vascular Bundle. (KNY)

a pith; *o* bark parenchyma; *i* cambium; *b–h* xylem; *k–n* phloem (inner bark); *b* annular vessel; *c* spiral vessel; *d* reticulated vessels; *g* pitted vessel; *e* wood parenchyma; *f* libriform fiber; *h* chambered wood cells; *k* cambiform cells; *l* sieve tubes; *m* bast parenchyma; *n* bast fibers.

---

[1] Angewandte Pflanzenanatomie, 331.

[2] DE BARY: *loc. cit.*, 177. MOLISCH: Zur Kenntniss der Thyllen, nebst Beobachtungen über Wundheilung in der Pflanze. Sitzb. Wien. Akad. 1888. REESS: Lehrbuch der Botanik, 1896, 88. TSCHIRCH: *loc. cit.*, 336. WIESNER: Anatomie der Pflanzen. Wien, 1898, 82.

From Figs. 134–136 (after REESS) it is evident that wood parenchyma adjoining the vessels furnishes the material for the formation of tyloses. A portion of the cell wall, endowed with an enormous power of growth, enters the lumen of the vessel through a pore and there develops into a bladder-like body, the walls of which may also become thickened and sclerenchymatized. Obviously the walls of the vessel take part in this development, which MOLISCH further describes as follows: "In the case of the first (spiral and annular) vessels the extraordinarily thin wall of the vessel is amalgamated with the wall of the adjoining parenchyma cell to form an apparently homogeneous membrane. This develops into the tylose. In the case of pitted vessels the membrane covering one of the one-sided bordered pits is the initial wall. The tylose results from the development of this membrane." Since tyloses, as a rule, are not separated from the parenchyma cells by a cross-wall, they are not true cells, but only

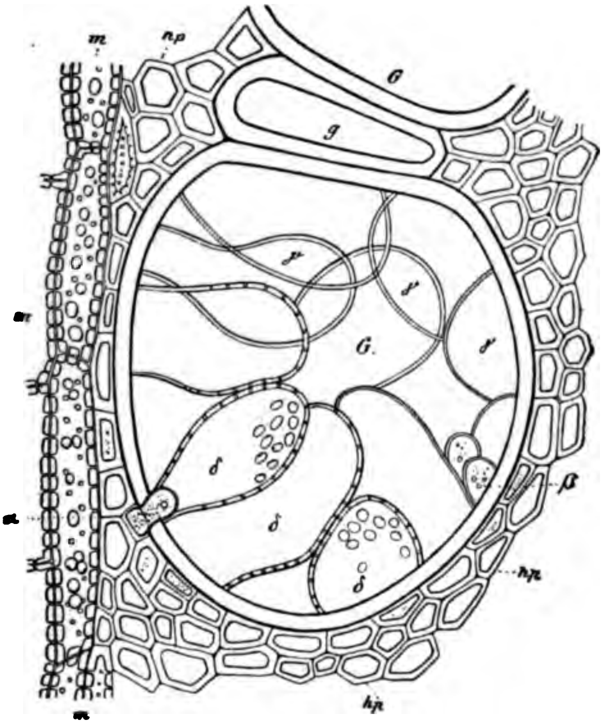


FIG. 134. Tyloses and Their Development. (REESS.)

Cross-section of the wood of *Vitis vinifera*, showing large vessel filled with old tyloses. At the left a young tylose growing out of a wood parenchyma cell. *hp* wood parenchyma; *m* medullary ray.

parts of cells or, more exactly, bladder-shaped excrescences on which, owing to their enormous development, the place of origin is often no longer visible. Tyloses may be produced at will by wounding branches.[1]

We will now consider the distribution of the vessels in cross-sections and the significance of this distribution as a means of identifying woods. Vessels as seen in cross-section are known in common parlance as pores. Two distinct classes of woods are formed by differences in the arrangement of these pores. In ring-porous woods numerous, usually closely crowded, vessels form a continuous ring of pores in the spring or early wood. Examples of ring-porous woods are ash, elm, and oak (see Figs. 139, 141, and 142). Diffuse-porous woods include those in which the vessels are more or less regularly distributed throughout the whole annual ring and are quite uniform in size; beech and maple (Figs. 151 and 153) are common examples. Various transitional and intermediate forms are of frequent occurrence (e.g., *Juglans*, *Carya*). The illustrations of the various forms are given in the analytical key on pp. 211–243. The vessels

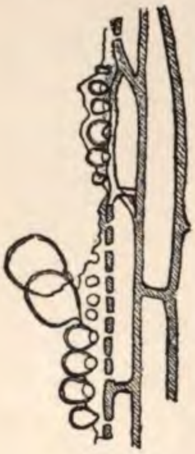


FIG. 135.

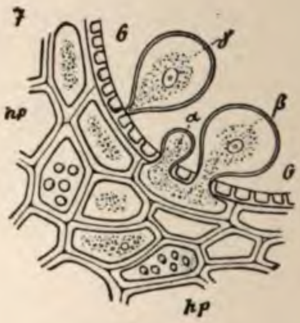


FIG. 136.

FIG. 135. Tyloses and Their Development. (REESS.)

Longitudinal section through the same wood as shown in Fig. 134. Tyloses have grown from the wood parenchyma through each pit into the vessel; the youngest above, those in the middle detached.

FIG. 136. Tyloses and Their Development. ×350. (REESS.)

Cross-section of vessel of *Cucurbita*, with young tyloses α and β growing from the wood parenchyma into the vessel.

---

[1] JOSEPH BÖHM: Sitzb. Wien. Akad. 1867. MOLISCH: *loc. cit.* REESS: Zur Kritik der Böhm'schen Ansicht über die Thyllen. Bot. Ztg. 1868.

(of the summer wood) situated outside of the rings of pores described above may show an unusual arrangement; they may be regularly distributed or arranged in various long, diagonal, or tangential wavy lines (e.g., *Ulmus*, *Celtis*), in which case, as a rule, they are accompanied by bands of wood parenchyma.[1]

Annual Rings.—From what has been said, it is evident that in ring-porous broad-leaved woods, as in coniferous woods, the annual rings are due to the arrangement of the vessels. The spring wood contains numerous, mostly large, pores; the summer wood fewer, very narrow pores which disappear entirely toward the boundary. As a consequence ring-porous woods usually have very distinct annual rings. Diffuse-porous woods, on the other hand, are not so simple in structure; still these, like conifers, show a tendency to form rings. In coniferous woods the tracheids last formed are very narrow, with thick walls and small lumens; in diffuse-porous broad-leaved woods the elements last formed in the summer wood are free from vessels and consist only of narrow, tangentially much flattened, radially arranged libriform cells with strongly thickened walls and small lumens (Figs. 137 and 138).

The statements which have been made with regard to the tracheids of conifers (p. 179) apply also to those of broad-leaved woods. It is obvious that these are usually recognized only in longitudinal sections; still the beginner should make it a special duty to study sections of each wood cut in the three directions. If the task is merely to identify a broad-leaved wood, a cross-section is in most cases sufficient, but in a microscopic investigation a study of the three sections is essential.

Cells of Medullary Rays.[2]—These are always pitted (Fig. 132, *k*; Fig. 138, *m*), usually radially elongated, and are arranged in vertical layers of various breadth and height.[3] There are, however, numerous woods the medullary rays of which are made up in part of cells which are elongated, not radially, but in a direction parallel to the axis of the stem. Between two rows, or stories, of these cells, arranged one above the other, occur narrow intercellular spaces. KNY [4] designates the radially elongated cells of medullary rays, the character of which depends, not on their elongated form, but on their loose arrangement, as palisade cells of the medullary rays; the vertical cells, on the other hand, as merenchyma cells. Excellent examples of woods with both kinds of cells are gray willow (*Salix fragilis*) and horse-chestnut (*Æsculus Hippocastanum* L.). In the wood of the gray willow, the order of arrangement from above downward in the single layer of cells of the medullary ray is something as follows: two rows of palisade cells, one row of merenchyma, one row of palisade cells, three rows of merenchyma, and finally two rows of palisade cells. **Kny** states that wherever the palisade cells immediately adjoin vessels, the walls of both are provided with large, irregularly polygonal, very slightly bordered pits which are not found in the palisade cells occurring in other parts of the medullary ray. The palisade cells adjoining the vessels are further distinguished from their neighbors on the right and the left by their larger radial diameter and also by the fact that the pits of their transverse and tangential walls are comparatively

---

[1] See also TSCHIRCH: Angewandte Pflanzenanatomie, 419.

[2] TSCHIRCH: Angewandte Pflanzenanatomie, 400.

[3] TUZSON (Ber. Deutsch. Bot. Gesell. 1903, 276) finds that the cells in the *Cupuliferæ* have spiral thickenings which may be torn away from the walls.

[4] Ein Beitrag zur Kenntniss der Markstrahlen dicotyler Holzgewächse. Ber. Deu Bot. Gesell. 1890, **7**, 176.

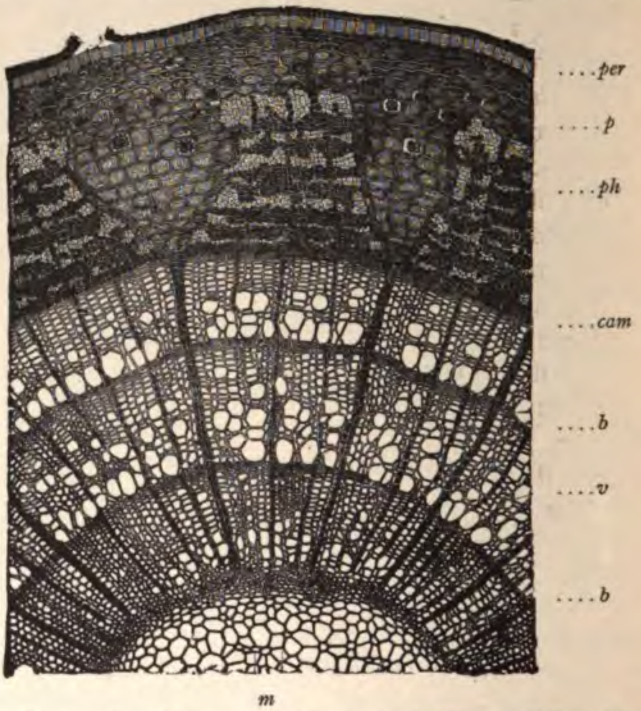


FIG. 137. Cross-section of Three-year-old Branch of *Tilia parvifolia*. (KNY.)
per cork; *p* bark parenchyma; *ph* phloem; *cam* cambium; *v* vessels; *b* borders of annual rings; *m* pith.

large. Large pits are not evident on the radial walls of the merenchyma cells whether these adjoin vessels or libriform cells.

Enlargements of the medullary rays, regarded by DE BARY as local hypertrophies, and designated by HARTIG as **Cell Streaks**, by NÖRDLINGER as **Pith Flecks**, and by ROSSMÄSSLER as **Medullary Repetitions**, are of regular occurrence in the wood of the alder and the mountain ash (*Sorbus*). According to HARTIG, these are due to the gnawing of the larvæ of an insect (*Tipula*), the passages first formed being later filled in by new cell tissue. HABERLANDT regards them as storehouses. "The smaller pith flecks [1] have the characters of local swellings of the medullary rays and indeed are enlargements of such tissues, but the larger spots may be more appropriately designated as abnormal wood parenchyma, since they have no relation to medullary rays and for the most part are not even elongated. These groups, islands, and streaks of abnormal wood parenchyma, which make their appearance in the cambium,[2] are

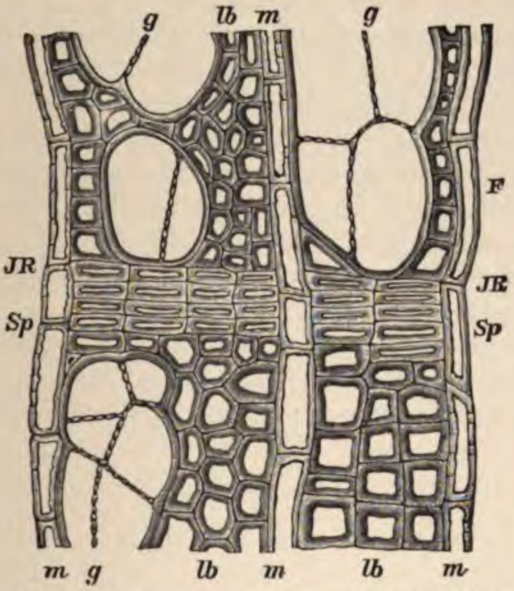


FIG. 138. Linden Wood in Cross-section. (T. F. HANAUSEK.)

g vessels; *lb* libriform cells; *m* medullary rays; *Sp* late libriform cells forming *JR* the annual ring. The cells change abruptly to strongly flattened forms arranged in distinct radial rows; commonly 4–6 rows are developed.—*F* spring wood of the next vegetative period.

---

[1] TSCHIRCH: Angewandte Pflanzenanatomie, 407.

[2] In my opinion, the cell streaks of HARTIG are not always identical with the medullary spots, but there are two distinct forms of parenchyma tissue.

often the starting-points or isolated centers of formation of lysigenous resin or gum glands such as form cherry gum (at least in part) and the balsam of many coniferous woods (e.g., *Abies balsamea*)."

The cells of the **Wood Parenchyma** are much more abundant in broad-leaved than in coniferous woods. They often form the tissues adjoining the vessels, are united to form radial (e.g., oak) or tangential (e.g., elm) lines, and serve during the resting season, or at least a part of that season, as storehouses of reserve material, particularly starch. Their walls are either non-porous or contain bordered pits.

The **Substitute Fibers** of SANIO are a special form of these cells. We have already learned (p. 179) that the cells of wood tissue are derived from the thin-walled, longitudinally elongated cells of the so-called cambium layer (Fig. 119). Wood parenchyma is formed by the division of the cambium cells by means of cross-partitions. If, however, no partitions appear and the cells preserve their original form, the wood elements are known as substitute fibers. These, like wood parenchyma, serve for conducting and storing reserve material and, in addition, may be of use in strengthening the tissues.

The **Pith** is present in the axis of all woods. As a rule it is reduced to a very small volume, although in some instances (e. g., elder) it is quite bulky. It is of little importance to the technical microscopist.[1]

TROPICAL BROAD-LEAVED WOODS.

The foregoing description of woods from the temperate zone applies in general to tropical woods, but the latter, as a rule, lack sharply defined annual rings, since in the tropics there is no resting period corresponding to our winter. However, in many tropical woods rings are evident, as these also grow by the formation of new cells in concentric layers; furthermore, true annual rings occur in some species.[2] Some woods, known as light or cork woods, consist in large part of wood parenchyma. These and the dyewoods described on subsequent pages illustrate the typical structure of tropical woods.

v. HÖHNEL[3] made the very important discovery that various woods, mostly tropical species, show in tangential section fine, uniformly distributed cross-striations which are evident either to the naked eye or else with the aid of a lens. These are due usually to the regularly arranged medullary rays, but in some cases are due wholly or in part to the pits. This tier-like structure is characteristic of woods of *Cæsalpinieæ*, of mahogany, of lignum-vitæ, etc.

---

[1] For further details see KASSNER: Ueber das Mark einiger Holzpflanzen. Diss. Berlin, 1884. TSCHIRCH: Angewandte Pflanzenanatomie, 424.

[2] When rings are present in tropical woods, it is a question whether these are annual rings or "season" rings. See TSCHIRCH: Angewandte Pflanzenanatomie, 421.

[3] Ueber stockwerkartig aufgebaute Holzkörper. Sitzb. Wien. Akad. 1884, **84**, 1.

B. Physico-technical Properties of Woods; Notes on Cell Contents.

A knowledge of certain physical and technical properties is indispensable in the identification of woods.[1]

1. **COLOR OF WOODS.**—In many woods the outer layers or annual rings are lighter in color than the central or inner layers. The outer light-colored layers, which are also the last formed, are known as the **Sapwood** or **Alburnum.**. Only the youngest layers of the sapwood, forming the conductive system, are of use in translocating sap, the inner layers serving merely for mechanical support.[2]

If all the layers of the wood have the characters of sapwood, the outer and inner layers throughout being the same in physical structure and chemical composition and of a uniform light color, the tree is known as a **Sapwood Tree**. Examples are hornbeam, birch, aspen, alder, sycamore, maple (*Acer Pseudoplatanus*), Norway maple (*A. platanoides*), hazel, and box (*Buxus sempervirens*).

If the inner layers of the trunk dry out without changing appreciably in color and hardness the tree is known as a **Ripewood Tree**. Ripewood is changed in physical condition, owing to the loss of moisture, but not in chemical composition. Examples are spruce, fir, red beech (*Fagus ferruginea*), field maple (*Acer campestre*), white thorn (*Cratægus Oxyacantha*), linden, and pear.

If the inner layers or rings of a tree differ physically and chemically from the outer, the former being dryer (with exceptions), harder, denser, firmer, darker-colored owing to the deposition of various substances (gums, resins, coloring substances), and more durable as regards decay, the wood forming the inner layers is known as **Heartwood** or **Duramen**, and the tree is known as a **Heartwood Tree**, provided the heartwood immediately adjoins the sapwood. The following are examples of this kind of tree: ash, oak, walnut (*Juglans*), cherry, plum, apple, chestnut, dogwood (*Cornus*), false acacia (*Robinia*), mulberry, plane tree (*Platanus*), white and black poplar, Riga pine (*Pinus silvestris*), larch, yew, juniper, cedar (*Pinus cedrus*), most trees foreign to Europe yielding heavy economic woods, and all dyewood trees.[1]

---

[1] MOELLER: Das Holz. 1884. NÖRDLINGER: Die technischen Eigenschaften der Hölzer.

[2] In addition to numerous articles by HARTIG the following are exhaustive: WIELER: Beiträge zur Kenntniss der Jahresringbildung und des Dickenwachsthums. Pringsheim's Jahrb. Wiss. Bot. **18**, 114. *Idem:* Ueber den Ort der Wasserleitung im Holzkörper dicotyler und gymnospermer Holzgewächse. Ber. Deutsch. Bot. Gesell. 1888, 6. 406.

In some woods a layer of ripewood is formed between the sap- and heartwood. Trees with wood of this description are known as **Heart-ripewood Trees.** The following trees belong in this class: elm, privet (*Ligustrum*), sallow (*Salix Caprea*), spindle tree (*Euonymus*), and buckthorn (*Frangula*).

The color of the sapwood is white or yellow, also reddish and greenish. The heartwood has commonly a definite, strongly marked color, such as yellow (e.g., fustic, candlewood), green, red, red-brown, brown, violet, black, etc. This color of heartwood is often of importance in determining quality—for example, the darker the heartwood of larch, the greater its durability; again, woods used for furniture and ornamental woodwork should be either uniform in color (e.g., ebony) or strikingly marked with veins, curls, etc.

2. **HARDNESS OF WOOD.**—The designations soft and hard wood are commonly used. There can be no doubt that white pine belongs to the former class and white oak to the latter, but an accurate definition of this property of hardness is exceedingly difficult. It may be said in general that the causes of hardness lie in the thickness of the cell walls, in the amount of infiltrated substance (lignin) in the walls, in the closeness of union of the wood elements, and in the compactness of arrangement in rings. The following examples of hard wood are arranged in the order of their hardness: pear, walnut (*Juglans regia*), beech, chestnut, maple, elm, oak, ash, plane, plum, nettle tree (*Celtis*), ailanthus, cherry, hornbeam (*Carpinus*), locust, dogwood, box, violet wood, quebracho, teak, ebony, lignum-vitæ, cocus wood, and the various "iron woods". Among the soft woods are conifers, linden, poplar, willow, birch, alder, and horse-chestnut.

Other technical properties, such as fineness, density, strength, flexibility, elasticity (of importance in woods used for sounding-boards, e.g., spruce, oak, beech), cleavage, etc., are of little importance to the microscopist.

---

[1] See J. GAUNERSDORFER: Beiträge zur Kenntniss der Eigenschaften und Entstehung des Kernholzes. Sitzb. Wien. Akad. 1882, **85**, 1. Abth. Januarheft, 10–41. According to GAUNERSDORFER, heartwood is formed by the infiltration of derivatives of the solid contents, chiefly starch, into all the elements of the wood. These derivatives are gums and resinous products. E. PRAËL: Vergleichende Untersuchungen über Schutz- und Kernholz der Laubbäume. Berlin, 1888.

The shrinking of wood is a noteworthy property. The water content of green wood, that is wood of newly felled trees, varies greatly, often amounting to half the weight of the trunk. Air-dry wood contains as a rule 7–15 per cent of hygroscopic water. The sapwood, at least in the outer part, is richer in water than the heartwood.[1]

If the water in the sapwood of the felled tree evaporates, the wood exhibits the phenomena of checking and warping. For example, a log sawed in half lengthwise develops a check to the heartwood, since the outer layers, being rich in water, shrink greatly, while the inner layers can not keep pace with this contraction. For the same reason a round log contains radiating checks, a four-sided timber commonly four checks; a board from the side of a log warps toward the sapwood side, a board from the middle of a log develops radial checks and warps toward the edges.

All woods, at least when fresh, have a distinct odor, which in conifers is due partly to turpentine and in sweet woods (violet wood, white sandalwood, incense wood) to essential oils.

The checks described above, also various rotting and freezing phenomena, and deformities due to irregularities, constitute the defects in woods. Gnarls and curls are important features of certain ornamental woods and veneers. They are due to undeveloped branches, irregularities of growth, wounds, and other causes.[2]

---

[1] HARTIG (Forstl. Naturw. Ztschr. 1894, **3**, 51) has shown that in oak the heartwood contains more water than the sapwood and that the layers of the heartwood adjoining the sapwood are poorest in water, but richest in air, while proceeding inward the water content increases and the air content diminishes. An oak 246 years old contained in different parts as follows:

Annual Rings.	Water.	Air Space.
246–226 (sapwood)	426	316
226–206 " "	366	377
206–186 (heartwood)	393	335
Inner heartwood	520	110

Notwithstanding these figures the heartwood was no longer active in conducting water, and HARTIG explains the high water content as follows (p. 52): "I regard the process the same as has been found to take place, in the course of time, when wood is soaked in water, namely, the air in the interior of the organs is gradually dissolved and carried off by the water. Undoubtedly a process of solution of this kind is promoted if both water and air are under increased pressure. Such a condition actually is present in the lower part of the trunk, at least periodically, when, during energetic osmosis in the roots and younger sap rings, a compression of the air takes place, which can not be without influence on the inner layers."

[2] See maple, p. 233.

The details with regard to the structure and properties of woods, given in this and the foregoing section, enable us intelligently to undertake their microscopic examination. First of all the technical microscopist will note the characters visible in cross-section to the naked eye or under the lens, such as the nature of the annual rings, the distribution of the vessels or "pores" (often the large "pores" visible to the naked eye are derived from several narrow adjoining vessels, e.g., walnut), and the form of the medullary rays. Next he will examine the general characters evident in the three sections, in which connection sketches will be found useful. This will show him the structure and development of the medullary rays, the distribution, size, and method of thickening of the vessels, and finally the distribution and structure of the wood parenchyma. He will then study systematically the details of the single histological elements; these may be advantageously isolated by maceration. The section on dyewoods furnishes us with interesting examples of this method of investigation.

Finally the investigator must learn the nature of the cell contents. Of the materials belonging to this class, of first importance is starch, which is laid down, at the end of the vegetative period, in the wood parenchyma, the pith, and the medullary rays; then tannin, resin, essential oils, gums, etc. Tannin is detected by iron salts, by which it is colored blue or green ("iron-blue" or "iron-green" tannin). Calcium carbonate[1] is of very frequent occurrence, filling the cells and vessels of many broad-leaved woods such as red beech, maple, elm, etc. Calcium oxalate is frequently found in so-called crystal fibers, occurring either as single crystals or as crystal rosettes.

The presence of starch in the store rooms (pith, medullary rays, wood parenchyma) may be of great importance in the examination of a wood. As a rule, no starch is present in the first part of the vegetative period, but in the autumn the tissues above named are filled with it. Therefore the presence or absence of starch, under certain conditions, serves incidentally to determine when the tree was felled. The presence of starch appears to be of especial importance in relation to the durability of the wood, chiefly as regards its power of resistance to the depredations of "worms", or, more correctly, the larvæ of certain wood insects. According to Emile Mer,[1] it is only the starch that is sought for and devoured by these larvæ. He further states that fir, spruce, poplar, and linden are entirely free of starch in winter, therefore they should be felled during that season to protect the wood from insect depredations. To free oak wood of starch, however, the trunk should be girdled twice, thus causing a gradual disappearance of that constituent. Red and white beech are also freed from starch by girdling. The sapwood is chiefly subject to insect depredations; the heartwood is commonly free of starch.

---

[1] H. Molisch: Ueber Ablagerung von kohlensaurem Kalk im Stamme dicotyler Holzgewächse. Sitzb. Wien. Akad. 1881, **84**, 7–27. The main facts brought out by this investigation are as follows: "In a not inconsiderable number of dicotyledonous woody plants calcium carbonate is deposited in the trunk, usually in the heartwood or other parts where the cells exhibit chemical and physical properties similar to those of the heartwood. Such parts are as follows: (1) the pith surrounded by heartwood; (2) dead, discolored wood about wounds; and (3) dead, discolored knots or branches. . . . Calcium carbonate is chiefly deposited in the vessels; single wood elements of all the other classes are also frequently filled with this salt." See also Wiesner: Anatomie und Physiologie der Pflanzen, 1898, 65.

The following analytical key is designed to aid the technical microscopist in the identification of the common woods. So far as possible the identification is by characters seen under a lens, but where these are insufficient the microscopic characters are briefly described. It is essential to have cross-sections of suitable size and thickness, which should be examined with both transmitted and reflected light. Nördlinger's cross sections and Burkart's collection of woods are of great value.

C. Analytical Key for the Identification of the Most Important Economic Woods, with Descriptions of the Species.[2]

1. Only tracheids present—no vessels (parenchyma in medullary rays)..Coniferous Woods 2
In addition to wood fibers (libriform), vessels (pores) always present. 14

---

[1] Nouvelles recherches sur un moyen de préserver les bois de la vermoulure. Ann. agron. 1899, **25**, 16.

[2] In the preparation of this key free use has been made of the following: A. Burgerstein: Vergleichend-histologische Untersuchungen des Holzes der Pomaceen. Sitzb. Wien. Akad. 1895, **104**, 723. *Idem:* Weitere Untersuchungen über den histologischen Bau des Holzes der Pomaceen, nebst Bemerkungen über das Holz der Amygdaleen. *Ibid.* 1896, **105**, 552. Burkart: Erläuternder Text zur Sammlung der wichtigsten europäischen Nutzhölzer. Brünn, 1883. T. F. Hanausek: Nutzhölzer. In Luerger's Lexikon der gesammten Technik, **6**, 566. Hartig: Die anatomischen Unterscheidungsmerkmale der wichtigeren in Deutschland wachsenden Hölzer. München, 4. Aufl. 1898. Moeller: Das Holz. Cassel, 1883. *Idem:* Nutzhölzer. In Dammer's Lexikon der Verfälschungen. Leipzig, 1886. Lodovico Piccioli: I caratteri per distinguere il legno delle Conifere. Estratto dalla Rivisto "Il Legno", Milano, 1904, Nos. 7, 8, 9. *Idem:* Il legname di Farnia e di Rovere (le querci italiane). Firenze, 1906. Filibert Roth: Timber, An Elementary Discussion of the Characteristics and Properties of Woods. U. S. Dept. Agr., Div. Forestry, 1895. Wilhelm: in Wiesner's Rohstoffe. 2. Aufl. 1903, **2**. The most comprehensive English work is Stone: The Timbers of Commerce. London, 1904.

2. Resin ducts absent or rare. 3
Resin ducts present. 11
3. No dark-colored heartwood—only ripewood.................... 4
With distinct heartwood. 5
4. Yellowish or reddish white, with only one kind of cells (parenchyma) in medullary rays. ....*Abies*
Reddish gray, with two kinds of cells in medullary rays (edges of medullary rays made up of tracheids)......................*Tsuga*

1. *Abies alba* Mill. (*A. pectinata* DC.), European Fir, Silver Fir, White Fir. Europe.—Yellowish white or reddish white; summer wood zone dark, thick; spring wood white, soft, spongy; boundaries of annual rings very distinct. Resin ducts (resin pores) absent or much scattered; in many annual rings entirely absent. Medullary rays not visible with lens; medullary cells of one kind with only simple (not bordered) pores (best means of distinction from spruce, see p. 186 and Fig. 124).—Soft, coarse, lustrous, very easily split, very poor in resin, warps more than spruce and is somewhat harder, extraordinarily durable in dry air.—Valuable for firewood, timber, boards, furniture, tools, masts (Austrian marine), shingles, in turnery, for various small articles; when cut radially, excellent for sounding-boards.
2. *Abies balsamea* Mill., Balsam Fir. Canada and northeastern United States; yields Canada balsam.—Color like last; summer wood zone very narrow; boundaries of annual rings distinct; resin ducts appear to be entirely absent.—Used for same purposes as last.—Other important lumber species are *A. grandis* Lindl. (Pacific region of North America) and *A. firma* S. et Z., Japanese Desert Fir.
3. *Tsuga Canadensis* Carr., Hemlock. Eastern United States and Canada. —Reddish gray or yellowish, rather compact, moderately hard, free from resin ducts; summer wood sharply defined, reddish brown; medullary rays 2–15 cells high, usually 5–10.—Used for timbers and railroad ties.

5. Tracheids always spirally thickened; medullary rays 0.22 mm. high; heartwood brown-red to almost bluish black..................*Taxus*
Tracheids with bordered pits only, never spirally thickened; medullary rays mostly 0.08 mm. high, seldom up to 0.13 mm. 6

4. *Taxus baccata* L., Yew. Europe.—Sapwood very thin, unequally distributed, on one side almost absent, yellowish white; heartwood dark brown-red, like fine mahogany; annual rings very narrow, finely and coarsely wavy; summer wood very dark; resin ducts always absent throughout. The broad spiral band of the tracheids covers the bordered pits as a tertiary thickening; tracheids narrow and strongly

thickened; wood parenchyma absent. (See p. 183 and Fig. 122.)—Heavy, hard, slightly lustrous; splits with difficulty, very durable, very elastic and tough, hence in olden times used for cross-bows, easily stained and takes good polish (German ebony is prepared from this or pear-wood). Also used for spigots, turned articles, lead pencils. Mottled wood from stem and root very beautiful.

5. *Taxus brevifolia* Nutt., Yew. Pacific region of North America.—Sapwood citron-yellow; heartwood light orange-red, of fine structure, hard, tough, rigid.—Used for timber and turned articles.

6. Tuberous pieces.................................*Araucaria*
Regular woody trunk.................................7

6. *Araucaria Bidwillii* Hook.—Probably yields the so-called "Pinkos" tubers, which, according to v. Höhnel, are the knots of the branches separated from the rotted wood. They are flesh-red to dark red, very hard, rich in resin, easily worked, and are excellent for turning.

7. With striking aromatic or resinous odor.................................8
Without odor or taste.................................10
8. *Hard Woods:* cells of medullary rays and parenchyma contain brightly lustrous, brown masses; medullary rays over 10–20 cells high. *Cupressus*
Soft Woods.................................9
9. Heartwood but little darker than the yellowish sapwood, very strongly odorous; medullary rays 2–5, seldom over 10, cells high. .*Chamæcyparis*
Heartwood gray-brown; cells of medullary rays in 1 sq. mm. of tangential surface 220–230.................................*Thuja*
Heartwood red-brown, bluish red, light violet; cells of medullary rays in 1 sq. mm. of tangential surface 300–330.................................*Juniperus*
Heartwood strikingly yellowish red brown; medullary rays 8–13, seldom over 20, cells high, with orange-red contents; sharp odor and peppery taste.................................*Libocedrus*

7. *Cupressus sempervirens* L. (*C. fastigiata* DC.), Common Cypress. Mediterranean regions.—Sapwood broad, reddish white; heartwood yellow-brown; annual rings coarsely wavy. Similar to red cedar in structure. Light, moderately hard, easily worked, with aromatic odor; very durable under water.—Used for timbers and boards, grape-vine stakes, and in ship-building.

8. *Chamæcyparis Lawsoniana* A. Murr., White Cedar, Port Orford Cedar, Oregon Cedar, Lawson's Cypress, Ginger Pine. Pacific region of North America.—Sapwood narrow, yellowish; heartwood but little

darker than sapwood, when resinified reddish, strongly odorous. Very durable.—Used for boards, timber, railroad ties, and fence posts.

9. *Thuja occidentalis* L., Arbor-vitæ, White Cedar. Eastern North America.—Sapwood yellowish white; heartwood light brown; annual rings coarsely and finely wavy; medullary rays visible under lens, more distinct than in *Juniperus*. Soft, splits with difficulty, durable, characterized by the camphor-like odor.—Usually too small for lumber, but used for posts, railroad ties, etc.—*T. gigantea* Nutt., Canoe Cedar of the Pacific coast of the United States, is similar to the last. Important for lumber.

10. *Juniperus communis* L., Common Juniper. A native of the Old and New World.—Sapwood yellow-white; heartwood reddish yellow to yellow-brown. Annual rings of variable breadth, mostly with coarse and fine waves, with a very narrow but distinct reddish-brown zone of summer wood. Medullary rays visible under lens, very thick, not straight; cells of medullary rays of one kind. Tracheids much narrower and slenderer than in *Abies* and *Pinus*.—Soft but compact, firm and tough, splits with difficulty, odor characteristic and agreeable, very durable in the open and in dry places, not subject to depredations of worms.—Used for carpenter work, turned articles, inlaying, whip handles, grape-vine stakes, and posts. Trinkets made from the wood with its fibrous bark are sold in Alpine summer resorts.

11. *Juniperus Virginiana* L., Red Cedar, Savin Juniper. United States east of the Rocky Mountains and southeastern Canada.—Sapwood yellowish; heartwood beautiful rose-red to brown-red and bluish red. Annual rings coarsely wavy; boundaries of annual rings almost purple-red; tracheids always broader than in common juniper; cells of medullary rays with blood-red resin (see p. 189 and Fig. 128).—Soft, light, splits easily, agreeable and lasting odor.—Extensively used for lead pencils; well adapted because of its durability for posts, and because of its odor for moth-proof closets and chests; also used in cooperage. The most valuable commercial cedar.

12. *Libocedrus decurrens* Torr., White Cedar, Incense Cedar. Pacific coast of the United States.—Characterized by the striking yellow-red color of the heartwood; summer wood zone narrow, only slightly darker than the broad spring wood; cells of medullary rays contain blood-red bodies dissolving in potash to an orange-yellow liquid.—Soft, very light, of very uniform structure.—Utilized for water pipes and furniture.

10. Heartwood of light brownish color; annual rings irregularly wavy, almost jagged; tracheids of spring wood with 2–4 rows of bordered pits on the radial walls; *without tannin* in cell walls......*Taxodium*
Heartwood bright red or red-brown, with very dark summer wood; medullary rays very easily seen under lens and nearly visible with-

out; tracheids in cross-section strikingly large; *with tannin* in cell walls..*Sequoia*

13. Taxodium distichum Rich., Bald Cypress, Black, White, and Red Cypress. Southeastern United States.—Sapwood narrow, yellowish; heartwood light brown to dirty brown, with very dark summer wood zone. Light but compact, extraordinarily durable, elastic. A beautiful wood employed in interior and exterior woodwork.

14. Sequoia sempervirens Endl., Redwood. Coast Range of California.—Wood very light and soft, but very durable. Easily recognized by the bright red heartwood with sharply marked annual rings and by the (for a coniferous wood) strongly developed, almost distinct medullary rays. Tracheids of spring wood very broad, with 2–3 rows of large bordered pits on their radial walls and somewhat smaller bordered pits on the tangential walls; cells of wood parenchyma contain beautiful ruby-red bodies, those of the medullary rings yellow-brown granular contents; cell walls react for tannin and sometimes show fine diagonal-spiral striations. The most valuable wood of the Pacific region for building and ornamental woodwork. Selected pieces with a mottled grain are much prized for veneering.

The big trees of California (*Sequoia Wellingtonia* Seem. = *S. gigantea* Dcne.) have wood of similar structure.

(2) Tracheids with spiral thickenings (as in *Taxus*).....*Pseudotsuga*
Tracheids without spiral thickenings......................... 12

15. Pseudotsuga mucronata Sudw. (= *P. Douglasii* Carr.), Douglas Fir, Yellow Fir, Red Fir, Oregon Pine. Pacific and Rocky Mountain regions of North America.—Sapwood thin; heartwood brown, changing to red, similar to larch wood; summer wood zone especially strongly developed in broad-ringed varieties. Very firm and hard.—Well suited for timber and masts.

Old and young wood of uniform light color (ripewood). ......*Picea*
With dark-colored heartwood.................................13

16. Picea excelsa Link., Spruce, Spruce Fir. Europe.—Very similar to fir wood, but easily distinguished by the numerous resin ducts visible on a fresh, smooth cross-section as pores and in longitudinal section as fine scratches, also by the medullary rays, which are of two kinds: (1) parenchyma cells with simple pores forming the interior of the ray, and (2) cross-tracheids with small bordered pits forming the upper and lower edges (see p. 186 and Figs. 123 and 125).—Yellowish white to reddish white, soft, coarse, lustrous, very easily split, with resinous odor; more durable than fir wood.—Important for firewood, lumber, sawed timber, such as beams, planks, and posts, for fine panelling; a narrow-ringed variety from Bohemia is a valuable resonance wood. (See pp. 190–193.)

17. Picea Mariana B. S. et P. = *P. nigra* Link., Black Spruce.[1] Eastern Canada and northern United States east of Mississippi River.—Not distinguishable from and used for the same purposes as *P. excelsa*. Other American species are *P. Canadensis* B. S. et P. (= *P. alba* Link.) and *P. Engelmanni* Engelm., both known as White Spruce, and *P. rubens* Sarg. (= *P. rubra* Link.), Red Spruce. The wood of the *P. rubens* is redder, more compact, and with narrower rings than the others.

13. Medullary rays with two kinds of cells; the edge cells with bordered pits (cross-tracheids); the inner cells, parenchyma with simple pores........................*Larix, Pinus Cembra*, and *P. Strobus*
Medullary rays with two kinds of cells; the edge cells jagged with zigzag thickenings. Color of heartwood develops on drying. Branches in whorls, hence in boards show distinctly their arrangement with reference to the annual rings.....*Pinus*, Group (*a*) and *P. Lambertiana*

18. Larix Europæa DC. (= *L. decidua* Mill.), Larch. Europe.—Sapwood yellowish white; heartwood, even in green wood, reddish brown to light carmine-red; summer wood broad, very dark, sharply outlined on both sides, in radial section strongly lustrous; resin ducts very numerous, not infrequently in groups (in *Pinus* much less numerous), in longitudinal section forming very delicate, narrow streaks.—Soft, coarse, more brittle than pine, easily split, highly elastic, very compact, shrinks little on drying, remarkably durable both in the air and under water. —Adapted for water construction, ship-building, cooperage, roof timber, shingles, sills, and heavy parts of machines. (See pp. 190–193.)

19. Larix occidentalis Nutt., Larch, Tamarack. Northern Pacific region of North America.—Wood not appreciably different from European larch; very compact and durable; thin rings (at least in sample at hand).

Pinus, Pine.[2] Color of heartwood develops on drying. Branches in whorls, hence in boards show distinctly their arrangement with reference to annual rings.
(*a*) Zone of summer wood broad, somewhat distinctly outlined against spring wood within. Edge cells of medullary rays with jagged walls.

20. Pinus silvestris L., Scotch Pine or Fir, Swedish Fir, Riga Pine or Fir, Wild Pine. Europe.—Sapwood very broad, yellowish to reddish white; green heartwood same color as sapwood, but on drying becomes brownish red; pith 4 mm. in diameter. Inner cells of medullary rays mostly with a row of large open pits on the radial side. Resin pores very numerous, mostly in middle and in last third of the annual ring (summer wood zone) often in a continuous line, in tangential sections forming broad yellow stripes. (See p. 187 and Figs. 116, 118, and 126.)—Soft, easily split, coarse, somewhat lustrous, easily torn by plane, with strong resinous odor, exceedingly durable.—An important wood for timber and boards; suited for water pipes; the best wood for large ships' masts; less suited for interior woodwork and furniture.

---

[1] "Black and white spruce, as applied by lumbermen, usually refer to narrow- and wide-ringed forms of the black spruce." (ROTH.)

[2] MOHR: The Timber Pine of the Southern United States. Washington, 1896.

21. ***Pinus nigra*** Arnold (=*P. nigricans* Host. =*P. pinaster* L. var. *Austriaca* Höss =*P. Laricio* var. *Austriaca* Aut.), Black Pine. Europe.—Wood only slightly different from that of preceding species. Sapwood very broad; annual rings very broad; resin pores much less numerous, much scattered, chiefly found in last third of annual ring, large and always with brown border, in tangential sections forming brown stripes. Often strongly resinified.—Like larch, one of the most durable building woods for water construction and sills; very valuable for shingles.

22. ***Pinus mughus*** Scop. (=*P. Montana* Mill. =*P. Pumilio* Hänke), Mountain Pine. Europe.—Wood similar to that of Scotch pine, but annual rings much narrower, excentric, and wood splits with difficulty.—Of comparatively little importance; used chiefly as firewood.

23. ***Pinus palustris*** Mill. (=*P. Australis* Michx.), Georgia Pine, Yellow Pine, Long-leaved Pine, Southern Pine, Hard Pine. Coast of southern United States from North Carolina to Texas.—Sapwood thin; heartwood reddish to reddish brown, by resinification dark brown, greasy, transparent. Summer wood very distinctly outlined, almost black-brown.—Wood for the most part narrow-ringed, very hard, heavy, very compact and tough, takes fine polish with greasy luster, very durable.—Much used for heavy timbers, flooring, water construction, etc. *P. ponderosa* Dougl., Bull Pine, of the Pacific and Rocky Mountain regions of the United States, is also known as Yellow Pine.

24. ***Pinus Tæda*** L., Loblolly Pine, North Carolina Pine, Slash Pine, Old Field Pine. Southeastern United States.—Sapwood thin, but broader than in last; heartwood deep brown, becoming strongly resinified as in *P. palustris*, but broader ringed. Wood of both species (Nos. *23* and *24*) distinguished from the European species Nos. *20–22* by the fact that the inner parenchyma cells of the medullary rays, on the radial walls adjoining the tracheids of the xylem, usually have groups of 2–6 (commonly 4) diagonally arranged, cleft-shaped pits.—The common lumber pine of southern United States.

Similar in structure are the woods of *P. resinosa* Ait., Norway Pine (northern United States), *P. echinata* Mill. (=*P. mitis* Michx.), Short-leaved Pine, Slash Pine, Yellow Pine, and *P. Cubensis* Griesch., Cuban Pine (the last two, southern United States).

(*b*) Summer wood narrow, without sharp boundary, gradually passing into the spring wood zone within.

25. *Pinus Cembra* L., Swiss Pine, Cembra Pine, Siberian Stone Pine. Europe.—Sapwood yellowish white; heartwood red-brown (when green, light-colored like the sapwood). Annual rings exceedingly uniform; dark-colored knots conspicuous in the light-colored wood. Resin pores large, numerous, detached, usually near or in the summer wood zone, in tangential section forming pronounced streaks. Outer (angle) cells of medullary rays with small pits, without jagged thickenings (Fig. 127).—Soft, one of the lightest of woods, splits easily, shrinks but little, takes beautiful polish, strongly odorous, durable.—Excellent finishing wood, much used for wainscoting, church and house furniture, Tyrolian carvings, and to some extent for shingles.

26. *Pinus Strobus* L., White Pine, Weymouth Pine. Europe, southern Canada, and northern United States.—Sapwood white or yellowish white; heartwood reddish yellow or brown, often lighter than that of *P. silvestris;* resin ducts numerous, as in *P. silvestris*, and distributed in like manner, but mostly occur singly, forming in tangential section very narrow streaks. Outer cells of medullary rays (as in *P. Cembra*) without jagged cells.—Soft, light, rather fine-grained, easily split and worked, but more brittle than the wood of *P. silvestris*, varies considerably according to habitat.—The best soft pine of North America. Used extensively for outside and inside woodwork, blinds, doors, etc.

27. *Pinus Lambertiana* Dougl., Sugar Pine Oregon and California.—Sapwood yellowish white; heartwood brownish. Resin pores diffuse, forming yellow streaks in longitudinal section. Outer (edge) cells of medullary rays with jagged thickenings; inner cells (parenchyma), on sides adjoining tracheids of the wood mass, with narrow elliptical or diagonal slit-pits.—Valuable for lumber.

14. (1) Wood of Dicotyledons: all woody tissues arranged about a central pith. 15
Stems of Monocotyledons: vascular bundles distributed through a ground tissue. 58

15. True annual rings present, mostly visible to the naked eye, seldom requiring magnification. (Mostly broad-leaved woods of temperate zone). 16
True annual rings absent, only indistinct rings present. (Mostly tropical broad-leaved woods). 49

16. Numerous, mostly closely arranged vessels forming a pore ring in the spring wood zone; ring-porous woods (in broader sense) (see Fig. 139). 17
Vessels more or less uniformly distributed through whole annual ring; diffuse-porous woods. 30

17. Early (pore ring) vessels of annual rings strikingly larger than late (of summer wood); ring-porous woods (in narrower sense). 18

Early (pore ring) vessels of annual rings not larger than late, but very numerous, closely arranged, therefore spring (early) wood zone loose, spongy, and light-colored.............................. 27

3. Vessels outside of pore ring uniformly distributed, or united only on the outer border so as to form short diagonal or tangential wavy lines... 19

Vessels outside of pore ring united so as to form long, distinctly tangentially arranged, sometimes branched, wavy lines or bands parallel to one another..................................... 24

Vessels outside of pore ring united so as to form radially arranged, often branched, groups.. 25

9. Medullary rays distinct or only visible with lens................ 20

Medullary rays not visible with lens; heartwoods............... 23

0. Annual rings broad; pore ring not sharply demarcated, gradually passing into summer wood zone............................. 21

Annual rings broad or narrow; pore ring sharply demarcated from the thick summer wood zone, the latter with small or few pores........ 22

. Wood commonly lighter; summer wood zone very rich in pores, those on the periphery of annual ring united to form short distinct wavy lines........................ . ...*Ailanthus*

Wood commonly darker; summer wood zone with few pores, which are detached or united in groups of 2 or 3, often radially arranged, not united at the periphery so as to form wavy lines........*Cedrela*

28. Ailanthus glandulosa Desf., Ailanthus. Europe and (introduced) America.—Sapwood yellowish; heartwood orange gray; pith large. Vessels diminish in size from within outward, open, in summer wood usually united in groups of several, mostly 3–4, the outermost joined to form short lines.—Heavy, hard, splits with difficulty, with satiny luster, durable in dry situations; often with apparent moon-shaped ring. Very useful for cabinet work and trinkets.

29. Cedrela odorata L., Spanish Cedar, Cigar-box Wood. West Indies.—Heartwood cinnamon-brown, changing to rust-red brown, polished tangential sections almost golden yellow, lustrous. Large vessels of pore ring in a very loose wood tissue; medullary rays almost wavy.—Well characterized by the aromatic odor; soft, light, splits easily but irregularly.—Employed for cigar boxes, sugar boxes, and as a substitute for mahogany. Other species of *Cedrela* are utilized for the same purposes.

2. Heartwood golden brown or orange-brown; pore ring very broad,

passing rather gradually into summer wood, although distinctly separated from it; pores open.......................... *Morus*[1]

Heartwood greenish yellow-brown, very hard; pore ring usually narrow in broad annual rings, but of same breadth as summer wood in narrow annual rings. Pores united toward outside, mostly stopped with tyloses . . . . *Robinia*

Heartwood red brown; pore ring of one row; medullary rays visible and invisible under lens (see No. 72) .... *Tectona*

Heartwood cherry-red; pores in summer wood commonly detached .... *Gymnocladus*

30. ***Morus alba*** L., White Mulberry.—Sapwood narrow, yellow-white; heartwood yellow-brown, becoming darker on standing.—Heavy, hard, lustrous, splits with difficulty, durable.—For woodwork, mosaics, trinkets, grape-vine stakes.

31. ***Morus nigra*** L., Black Mulberry.—Like the preceding; often subject to damage (ring coat). Pores sometimes stopped.—Uses same as for preceding.

32. ***Morus rubra*** L., Red Mulberry. United States.—Heartwood orange-brown.—For cooperage, ship-building, and farm implements.

33. ***Robinia pseudacacia*** L., Black Locust, Yellow Locust. Europe and eastern United States.—Sapwood very thin, yellowish; heartwood greenish yellow-brown.—Hard, splits with difficulty, trunk wood elastic, branch wood brittle, very durable, takes fine polish.—For building, posts, stakes, spokes, shoe pegs, pins, brandy casks, turned articles, furniture.

34. ***Gymnocladus dioicus*** K. Koch. (=*G. Canadensis* Lam.), Kentucky Coffee Tree, Coffee Nut. Middle West of United States.—Sapwood yellow; heartwood cherry-red to red-brown. Has limited use in cabinet-making.

23. (19) Pore ring broad with large pores; summer wood zone sharply demarcated, with small pores, 3–4 of which are united to form short, close, single-rowed, tangentially and diagonally arranged groups. *Fraxinus*

Pore ring very narrow, almost one-rowed; numerous, fine, tangential lines in summer wood; heartwood brownish.......... *Hicoria* (*Carya*)

Pore ring very narrow; in summer wood numerous, very fine, tangential lines, much finer than the medullary rays; sapwood broad, cream colored; heartwood blackish......................*Diospyros*

---

[1] Most authors state that the pore ring is not sharply demarcated, but passes gradually into the summer wood. If, however, *Morus* is compared with *Ailanthus*, a marked distinction may be observed. There is certainly a gradual transition; it is not, however, striking, owing to the much smaller size of the pores in the summer wood and their smaller number.

35. *Fraxinus excelsior* L., Common Ash (Fig. 139). Europe.—Sapwood yellowish white; heartwood light brown; between the two, light-colored ripewood. Wood in longitudinal section strikingly broad-striped (broad, sharply demarcated pore ring); pith large.—Heavy, hard, lustrous, splits with difficulty, firm, tough, elastic, takes good polish, warps but little, not durable in the open or under ground.—An excellent and beautiful wood for cabinet work, turnery, for planks and boards, carriage poles and shafts, carriage bodies, walls of railroad cars, agricultural implements (ladders, rakes, forks), lance shafts, axe handles, hop poles, whip handles, canes. The mottled wood much prized for veneering.

30. *Fraxinus Americana* L., White Ash. Nova Scotia to Texas and Minnesota.—Used for finishing lumber, in ship-building, in the construction of cars, wagons, carriages, etc., in the manufacture of farm implements, machinery, and especially of furniture of all kinds; for barrels, baskets, oars, tool handles, hoops, clothes pins, and toys (ROTH).

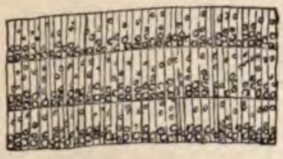


FIG. 139.

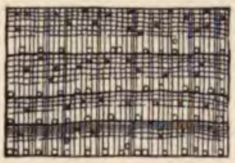


FIG. 140.

FIG. 139. Common Ash (*Fraxinus excelsior*). Cross-section under Lens. (T. F. HANAUSEK.)

Ring-porous, pore ring broad with large pores; summer wood with small pores united short one-rowed diagonally and tangentially arranged groups.

FIG. 140. Hickory (*Carya* sp.). Cross-section under Lens. (T. F. HANAUSEK.)

Pore ring very narrow with very large pores in one row; summer wood with very small es and numerous fine tangentially arranged lines of wood parenchyma.

The woods of the following American species are put to the same uses as white ash: *F. Pennsylvanica* Marsh. (=*F. pubescens* Lam.), Red Ash; *F. nigra* Marsh. (=*F. sambucifolia* Lam.), Black Ash; *F. quadrangulata* Michx., Blue Ash; *F. Pennsylvanica* var. *lanceolata* Sarg. (=*F. viridis* Michx.), Green Ash; *F. Oregona* Nutt., Oregon Ash.

37. *Hicoria glabra* Britt. (=*Carya porcina* Nutt.), Pignut Hickory (Fig. 140). Eastern North America.—Sapwood yellowish white; heartwood brownish, resembling oak. Pores of pore ring very large;[1] in summer wood

---

[1] Distribution of vessels nearly the same as in *Juglans* (see No. 73). The false pore in *Hicoria* is due to the larger pores in the spring wood, those of the summer wood g invisible to the naked eye. The same arrangement of vessels occurs also in *Juglans rea*, which may also be placed here.

numerous light, fine, peripheral, parallel lines of wood parenchyma form with thinnest medullary rays a fine network.—Very heavy, hard, elastic, tough, and durable.—Valuable for wagon parts and tool handles; not used in building.

38. *Hicoria ovata* Britt. (=*Carya alba* Nutt.), Shagbark or Shellbark Hickory. North America east of Mississippi River.—The best hickory wood, very useful for spokes. The wood of *Hicoria alba* Britt. (=*C. tomentosa* Nutt.), Mockernut Hickory, is also of importance.

39. *Diospyros Virginiana* L., Persimmon. Eastern and central United States.—Sapwood very broad, yellowish white, cream-colored; heartwood black-brown.—Hard, heavy, very dense and tough, takes a fine polish.—Used for turned articles, shuttles, plane stocks, shoe lasts, and after staining as a substitute for ebony.

24. (18) Heart-ripewoods. Sapwood yellow-white; ripewood reddish; heartwood brown. Pore ring relatively broad with large pores, somewhat sharply demarcated, the wavy lines in summer wood crowded, numerous, band-like. . . . . *Ulmus*
Sapwood thick, yellow-white to white; heartwood brownish gray. Pore ring relatively narrow, mostly only 1–2-rowed, the pores in the summer wood less closely united into lines, in the middle of the annual ring often irregularly distributed, only at the periphery united into narrow, sometimes branched, bands. . . . . *Celtis*
Pore ring broad; all kinds of medullary rays (see *Quercus Cerris*, No. *51*)

40. *Ulmus Americana* L., White Elm, Water Elm. Central and eastern North America.—Sapwood broad, whitish; heartwood brown; both with shades of gray and red. *Pore ring with scarcely more than a single row of pores.*—For wagon construction, ship-building, barrels, agricultural implements. Beautiful grain for furniture.

41. *Ulmus Thomasi* Sarg. (=*U. racemosa* Thomas), Rock Elm. Eastern and central North America.—*Pore ring with scarcely more than a single row of pores*, which, however, are *much smaller than in No. 40.*—More valuable than white elm; well suited for hubs.

42. *Ulmus fulva* Mich., Red Elm. Eastern North America.—*Pore ring consists of several rows of pores.*

43. *Ulmus campestris* L. (*U. campestris α-glabra* and *β-suberosa*), Field Elm, Common European Elm (Fig. 141). Europe.—Sapwood thin, yellow-white; heartwood brown-red. Wavy lines in summer wood made up of simple pore rows which often are interrupted (Hartig).—Heavy, hard, compact, elastic, very tough, splits with difficulty, very durable, often curled.—Excellent for wagon parts such as axletrees, felloes and other bent parts, and especially for cannon carriages; owing to the beautiful grain, used for gun stocks and for turned articles such as tobacco pipes.

44. *Ulmus effusa* Willd., White Elm. Europe.—With broad band-like wavy lines in summer wood, tissue consequently looser than in preceding. —Although less valuable than preceding, the mottled wood is highly prized.

45. *Celtis Australis* L., Nettle Tree, Honey Berry. Europe.—Sapwood broad, almost white; heartwood gray-brown. Pores of summer wood very small, less crowded than in *Ulmus*, united into lines which are often zigzag; summer wood consequently very dense.—Hard, coarsely fibrous, heavy, difficultly split, elastic, exceedingly tough. Well suited for whip handles, rudders, carriage shafts, wind instruments, fishing-rods. The wood of the North American species *C. aspera* Desf. has a still denser structure.

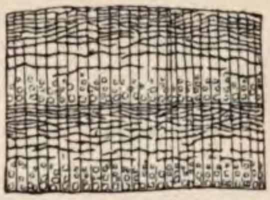


FIG. 141. Field Elm (*Ulmus campestris*). Cross-section under Lens. (T. F. HANAUSEK.)

Ring-porous, pore ring broad with large pores, sharply defined; vessels outside of the pore ring united to form long, distinct, tangentially arranged, sometimes branching, wavy lines.

25. (19) All kinds of medullary rays present—distinct, visible and invisible under lens . . . . *Quercus*
All medullary rays invisible under lens. . . . . *Castanea*
All medullary rays distinct to naked eye, strikingly broad. 26

Quercus, Oak. In the world's commerce four well-defined geographical groups of oaks are of importance: I North American, II Central European, III Mediterranean and Western Asiatic, and IV Eastern Asiatic.

As regards the histological structure of the wood the species may be divided into two classes: (1) ring-porous and (2) diffuse-porous (including most of the Mediterranean species). Most of the species have in the summer wood, in addition to very broad and distinct medullary rays, light, radially arranged, sometimes forked, tail-like markings and much finer, very delicate, tangentially arranged wavy lines distinctly visible under lens. Both of these are formed by wood parenchyma (with vessels invisible even under lens).

I. NORTH AMERICAN SPECIES.

"Three well-marked kinds, white, red, and live oak, are distinguished and kept separate on the market. Of the two principal kinds white oak is the stronger, tougher, less porous, and more durable. Red oak is usually of coarser texture, more porous, often brittle, less durable, and even more troublesome in season-ing than white oak. Live oak, once largely employed in shipbuilding, possesses all the good qualities (except that of size) of white oak, even to a greater degree. It is one of the heaviest, hardest, and most durable building timbers of this country; in structure it resembles the red oaks, but is much less porous." (Roth.)

46. *Quercus alba* L., White Oak. Central and eastern United States and southeastern Canada.—Pores of pore ring very large, but mostly in 1–2 rows; heartwood light gray-brown; radial streaks very distinct, almost always with sinuous course.—Very hard and tough, elastic, much prized for interior woodwork, furniture, and cooperage.
Similar to the last are the woods of *Q. platanoides* Sudw. (= *Q. bicolor* Willd.), Swamp White Oak, same range as *Q. alba*; *Q. lobata* Née, White Oak of the Pacific region; *Q. lyrata* Walt., Over-cup Oak, central and eastern United States; *Q. macrocarpa* Michx., Bur Oak, central and eastern United States and southeastern Canada.

47. *Quercus rubra* L., Red Oak, Black Oak. Central and eastern United States and southeastern Canada.—Inferior to white oak.—Used for cooperage.

48. *Quercus Virginiana* Mill. (= *Q. virens* Ait.), Live Oak. Virginia to Texas. This tree yields the valuable live oak of eastern United States.

For descriptions of other species see F. Roth: Timber, p. 81.

II. Central European Species.

49. *Quercus robur* L. (= *Q. pedunculata* Ehr.), British Oak, Common Oak[1] (Fig. [illegible]). Wood parenchyma with very small vessels forms (1) radially arranged, sometimes forked, distinct tail-like streaks and (2) tangentially arranged, much finer, delicate, but distinct, wavy lines.

50. *Quercus sessiliflora* Salisb., Chestnut Oak, Durmast Oak (Fig. [illegible]). The radial streaks of wood parenchyma are long and narrow; the tangential lines are [illegible]

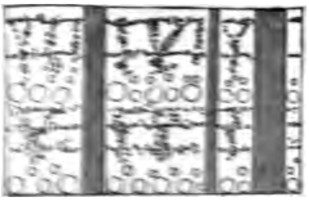


Fig. [illegible]. British Oak (*Quercus Robur* = *Q. pedunculata*). Cross-section under Lens. (T. F. Hanausek.)

Ring-porous, pore ring with very large pores, sharply outlined against the summer wood; wood parenchyma in radial tail-like streaks and tangential wavy lines. Medullary rays broad and narrow.

---

[1] [illegible] Dissert., Berlin. [illegible]

wood than in the preceding species. Although this distinction is noted by other authors, the two species have evidently been confused.

51. *Quercus Cerris* L., Bitter or Turkey Oak (Fig. 144).—Differs from the preceding species in that the radial streaks of wood parenchyma are very rarely present, while the tangential lines are developed so as to form somewhat pronounced bands. In the analytical key this wood belongs really to No. 24 (after *Celtis*).—The heartwoods of *Q. robur* and *Q. sessiflora* are among the most durable of woods for use above and below ground as well as under water, and are very hard, heavy, coarse, split easily and somewhat smoothly. They make the best railroad ties and are also employed for parts of machines, stamps in oil mills, heavy furniture, parquetry, wine casks, mash vats, wagon parts; light-colored, long-fibrous oak with broad annual rings (but narrow pore circle) is well adapted for ship-building.

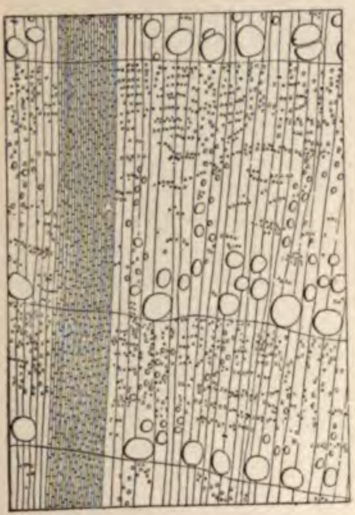


FIG. 143.

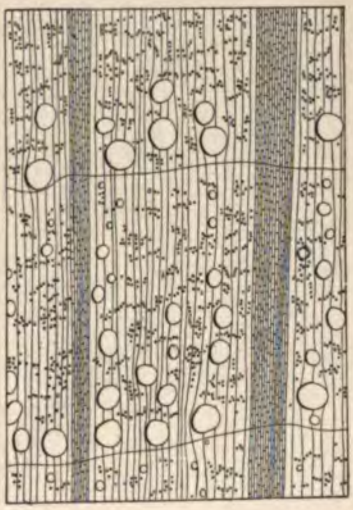


FIG. 144.

FIG. 143. Tanbark Oak (*Quercus sessiliflora* Salisb.). Cross-section under Lens. (PICCIOLI.)

FIG. 144. Bitter Oak (*Quercus Cerris* L.). Cross-section under Lens. (PICCIOLI.)

52. *Quercus conferta* Kit., Hungarian Oak, Gipsy Oak (Fig. 145).—Wood much like that of *Q. robur;* splits with difficulty; for water, earth, and mine construction; well suited for railroad ties, but not for furniture.

III. MEDITERRANEAN SPECIES.

These are distinguished from the preceding species by the *diffuse-porous wood*, the less distinct annual rings, and the radially arranged, light, wavy streaks of wood parenchyma (with vessels not visible under lens), giving the cross-section a clouded appearance.

53. *Quercus Ilex* L., Evergreen Oak (Fig. 146).—Very heavy, dense, an hard, difficult to work.—Serves for firewood; the root wood used fo furniture.

54. *Quercus coccifera* L., Kermes Oak (Fig. 147).—Wood resembles tha of preceding species.

55. *Quercus suber* L., Cork Oak (Fig. 148).—Wood intermediate between ring-porous and diffuse-porous oaks, dense, and heavy.

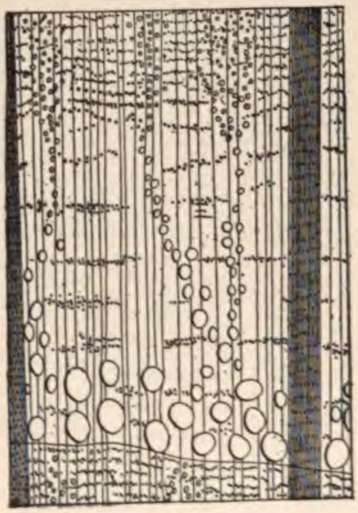


FIG. 145.

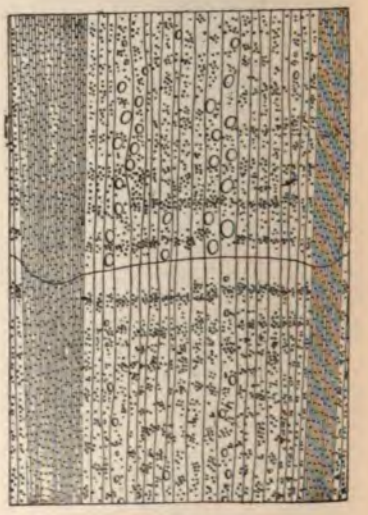


FIG. 146.

FIG. 145. Hungarian Oak (*Quercus conferta* Kit.). Cross-section under Lens. (PICCIOLI.)

FIG. 146. Evergreen Oak (*Quercus Ilex*). Cross-section under Lens. (PICCIOLI.)

56. *Castanea sativa* var. *Americana* Watson, Chestnut. North America.—Scarcely distinguishable from the species; splits easily.— Much used for railroad ties, telegraph poles, piles, heavy timbers, interior woodwork, and cooperage.

57. *Castanea sativa* Mill., European Chestnut.—Resembles oak, but distinguished by the absence of distinct or even visible medullary rays. —Rather hard, easily split, durable under water, but more so in dry air. —Used for roof timbers, water work, grape-vine stakes, cask hoops, bentwood furniture, and railroad ties.

26. Vessels very large, the whole annual ring, up to a narrow spring zone, with numerous large pores; wood not strikingly colored (see Figs.

134 and 135).. *Vitis*
Pore ring very narrow; sapwood lemon-yellow; heartwood blue-red.. *Berberis*

58. Vitis vinifera L., Grape Vine.—Does not grow to a large size; pith very large.—Flexible, very elastic, light, externally fibrous.—Used for walking-sticks.

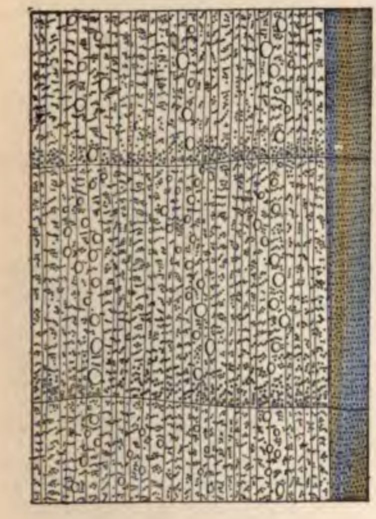


FIG. 147.

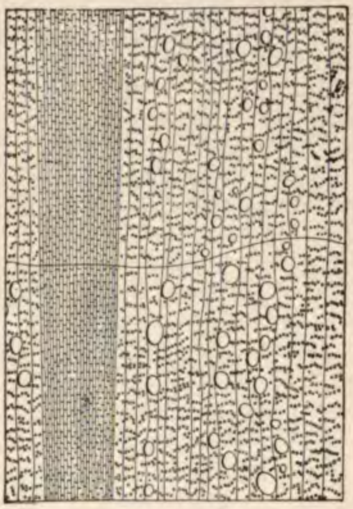


FIG. 148.

FIG. 147. Kermes Oak (*Quercus coccifera* L.). Cross-section under Lens. (PICCIOLI.)
FIG. 148. Cork Oak (*Quercus suber*). Cross-section under Lens. (PICCIOLI.)

59. Berberis vulgaris L., Barberry.—The fresh wood well characterized by its color and disagreeable odor.—Chips, especially of root wood, used as dye.

27. (17) Medullary rays distinct with or without lens; vessels in summer wood uniformly distributed.................................. 28
Medullary rays not visible under lens; heartwood often strikingly colored.. 29
28. Pith up to 10 mm. in diameter; wood yellowish white; medullary rays very distinct..*Sambucus*
Pith small; heartwood red brown to black-brown..........*Prunus*[1]

---

[1] Often classed with diffuse-porous woods. See WILHELM: Wiesner's Die Rohstoffe. 2. Aufl. 1903. **2**, 922, 923.

60. *Sambucus nigra* L., Black Elder.—The numerous, broad medullary rays and the light color of the wood very characteristic.—Hard, compact, warps strongly.—Used for turned articles and combs.

61. *Prunus domestica* L., Plum.—The *Prunus* woods are much alike and difficult to distinguish. They are distinguished from similar woods of pomes by the pore ring, which is absent in the latter. Sapwood thin, yellowish white; heartwood brown-red (a thin section with transmitted light, blood-red); annual rings wavy; pore ring lighter, not sharply demarcated, but passing gradually into the summer wood; medullary rays distinct or visible under lens, very narrow, very numerous, partly short, forming in radial section panel-like markings, partly broad, and wavy.—Hard, heavy, not durable.—Well adapted for interior woodwork and turning.

62. *Prunus insititia* L., Bullace.—Similar to last, but denser. Medullary rays visible only under lens.

63. *Prunus avium* L., Sweet Cherry, Mazard Cherry (Fig. 149).—Sapwood reddish white; heartwood light yellow-brown; annual rings broad, nearly free from waves; medullary rays visible under lens or invisible, in the former case light, irregularly distributed; all pores very small, pore ring passing gradually into summer wood.—Not quite so hard or heavy as preceding, easily split.

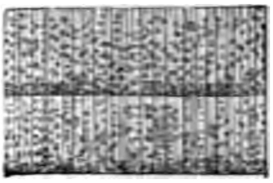


FIG. 149. Cherry (*Prunus avium*). Cross-section under Lens. (T. F. HANAUSEK.)

Ring-porous, the first (pore ring) vessels of the annual ring numerous, not larger than the later vessels, very closely crowded, the pore ring gradually passing into the summer wood. Medullary rays very numerous, barely visible and invisible.

64. *Prunus Cerasus* L., Sour Cherry, Morello Cherry.—Annual rings narrower than in preceding; pore ring a light, narrow strip; in other respects like preceding.

65. *Prunus Mahaleb* L., Mahaleb Cherry, Turkish Cherry, Baden Cherry.—Sapwood reddish white; heartwood light brown, becoming much darker on exposure; pore ring broad.—Wood of cultivated shrub characterized by the agreeable odor of coumarin.—Utilized for tobacco pipes, walking-sticks, and trinkets.

66. *Prunus Armeniaca* L., Apricot.—Distinguished from last by the rather sharply demarcated pore ring, the large pores, and the almost distinct medullary rays. Heartwood mahogany-brown.

The wood of the almond (*Amygdalus communis* L.) is very similar.

67. *Prunus serotina* Ehrh., Cherry, Wild Cherry. North America.—Approaches the diffuse-porous woods; pore ring, only here and there distinct, passes at once into the richly porous summer wood; heartwood red-brown, dense; medullary rays distinct but fine, very closely crowded, in cross-section lighter than the rest of the wood.—Takes a fine polish; can be stained to imitate closely mahogany and ebony; valuable for interior woodwork, furniture, boats, etc.

68. Prunus Padus L., Bird Cherry. Europe.—Heartwood brown-yellow; annual rings broad; medullary rays visible under lens, rather uniformly developed.—Very dense, hard, easily polished.

29. Heartwood orange-red or yellow-red; vessels so small as to be scarcely visible under lens.................................. *Rhamnus*

Heartwood golden yellow, changing with potash to carmine-red and with hydrochloric acid to vermilion-red; vessels distinct under lens. *Cotinus coggygria* Scop.

Heartwood red brown; sapwood light brown; pores outside of pore ring detached, often filled with tyloses and resin............ *Tectona*

69. Rhamnus cathartica L., Buckthorn. Europe.—Sapwood very thin, yellowish or greenish yellow; heartwood orange-red, longitudinal section characterized by the high silky luster. In cross-section shows light-colored, very distinct pore rings, vessels outside of pore ring joined to form light-colored, sinuous, more or less united bands and lines, giving the section a clouded appearance (HARTIG).—Rather hard, heavy, durable.—Used for turned articles.

70. Rhamnus Frangula L., Alder Buckthorn, Black Alder. Europe.—Sapwood light yellow; heartwood golden red; vessels outside of pore ring diffuse, exceedingly small, pore ring much less distinct than in preceding.—Almost soft, easily split.—Mostly used for gunpowder charcoal.

71. Cotinus coggygria Scop. (*Rhus Cotinus* L.), Young Fustic.—Sapwood thin, white; heartwood golden yellow, often with alternating yellow and yellow-green annual rings. Pores distinct under lens; small, radial or diagonal, light-colored streaks run from pore ring to periphery.—Moderately hard, easily split, strongly lustrous.—A well-known dye-wood. See p. 246 and Figs. 156 and 158.

72. Tectona grandis L. fil., Teakwood. East Indies.—Sapwood light brown; heartwood red-brown, becoming much darker on exposure, with broad and much narrower, finely wavy ring zones, several of the narrow zones usually occurring in succession. Pore ring very distinct, light-colored, generally only one-rowed; boundary lines of annual rings very thick, dark brown to blackish, the wood between them uniformly brown. Detached pores strikingly large, many stopped up, forming in radial section marked furrows. Medullary rays visible under lens, light-colored, intervening rays not visible under lens, many not straight, but with small waves.—Owing to the one-rowed pore ring, the pores of which are mostly larger and not closely crowded, this wood may also be classed with "ring-porous woods in the narrower sense" (17). Remarkable for the white cell contents, consisting of calcium phosphate —Freshly cut wood has disagreeable odor.—The best wood for ship-building; used also for ornamental woodwork and oriental furniture. (The description is based on an authentic sample kindly furnished by Prof. H. Greenish, of London.)

30. (16) Pores very large, visible with naked eye, open, somewhat rare; indications of ring pores; heartwood deep brown with blackish waves, or else light gray-brown with faint waves.................. *Juglans*
Vessels not visible with naked eye 31

73. ***Juglans regia*** L., European Walnut (Fig. 150).—Sapwood broad, gray-white; heartwood brown or blackish brown, with marked blackish lines and streaks. The strikingly large pores are made up of several radially arranged vessels; the remainder of the pores in the annual ring of rather uniform size, becoming small only at the periphery. In very broad annual rings the first rows of spring wood form a kind of pore ring. Very fine cross-lines occur in summer wood, forming with the medullary rays a delicate network.—Heavy, hard, easily split, very durable in dry air, takes beautiful polish.—Excellent for furniture, turned wares, and gun stocks.

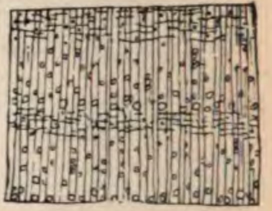


Fig. 150. European Walnut (*Juglans regia*). Cross-section under Lens. (T. F. Hanausek.)

Diffuse-porous, the first pores (consisting of several vessels) very large and open, rather few; the remainder in the annual ring uniformly large, becoming smaller only at the periphery. Very fine cross-lines of wood parenchyma in summer wood. Suggestions of pore rings; these in *Carya* are much more distinct.

74. ***Juglans nigra*** L., Black Walnut. Central and eastern North America.—Heartwood dark brown, often reddish, more uniform in color than in preceding species and with fewer vessels.—Formerly much used for furniture and interior woodwork.

75. ***Juglans cinerea*** L., Butternut, White Walnut. Central and eastern North America.—Softer and more easily worked than preceding species; color light gray-brown.—"Used chiefly for finishing lumber, cabinet work, and cooperage" (Roth).

31. All medullary rays distinct, broad or narrow..................... 32
Medullary rays of other forms................................ 33

32. Medullary rays rather broad, of nearly uniform breadth, very numerous; wood and medullary rays reddish, medullary rays darker (especially in radial section)............................*Platanus*
Medullary rays very fine, exceedingly numerous; wood yellowish; medullary rays almost white..........................*Liriodendron*

76. ***Platanus occidentalis*** L., Sycamore, Buttonwood, American Plane Tree. Eastern United States.—Annual rings of different breadths, boundary zones narrow, forming in transmitted light dark lines bowed out somewhat at the medullary rays. The broad medullary rays closely

crowded, lustrous, of about the same breadth as the intervening tissue; radial section strongly lustrous, owing to the numerous medullary rays. Pores small, uniformly distributed through whole annual ring.—Hard, heavy, splits with splintery fracture not durable in open.—A beautiful wood for furniture and interior woodwork; used also for cooperage and boxes.

77. ***Liriodendron tulipifera*** **L.**, **White Wood, Tulip Wood,**[1] **Yellow Poplar.** Central and eastern United States.—Sapwood whitish, becoming brownish on exposure; heartwood dirty green, annual rings very finely striate.—Coarsely fibrous, soft, easily split, lustrous.—A valuable wood for carriage-building, interior woodwork, furniture, toys, etc.; has also been used for paper-making (see p. 293).

33. Medullary rays unequally developed, some distinct or apparently distinct, the remainder mostly invisible under lens [2]............. 34
All the medullary rays (in reflected light) visible under lens, very fine, uniformly developed.................................... 36
All the medullary rays (in reflected light) invisible under lens (in *Betula* almost visible)...................................... 39

34. Pith flecks (see p. 205) never present.......................... 35
Pith flecks present..*Alnus*
(If no pith flecks are visible, *Alnus* is distinguished from *Carpinus* by the dark color of the wood (only sapwood) and from *Fagus* by the much broader summer wood zone.)

78. ***Alnus glutinosa*** **L.**, **Black Alder.** Europe.—Sapwood reddish gray, often with dark-brown pith flecks. Boundaries of annular rings often not very distinct; broad medullary rays partly distinct, partly apparently distinct, and then disappearing, in tangential section remarkable because of their great height. Vessels very small, commonly radially arranged.—Soft, light, easily split, very durable under water, brittle.—Used for water and mine construction, turned articles, inlaying, wooden shoes, cheap lead pencils; mottled pieces used for pipe bowls.

79. ***Alnus incana*** **L.**, **White Alder.** Europe.—Broad medullary rays much less numerous; pith flecks for most part absent; wood strongly lustrous; in other respects like preceding species.

35. The broad (true) medullary rays distinct; wood reddish ....*Fagus*
The broad (false) medullary rays distinct; wood white...*Carpinus*

---

[1] In England the term tulip wood is applied to *Physocalymna scaberrimum* Pohl. (from Brazil), in Australia to the wood of *Harpulia pendula* Planch. (*Sapindaceæ*), and in the United States to the wood of the cucumber tree (*Magnolia acuminata*).

[2] The Mediterranean oaks also belong under this division (see p. 225).

80. ***Fagus Americana*** **Sweet. (=*F. ferruginea* Ait.), American Beech. Eastern United States.—Very similar in structure to following species. Serves for flooring, in furniture and carriage building, for tool handles, etc.**

81. ***Fagus sylvatica*** **L., Red Beech, Copper Beech (Fig. 151). Europe.—Described by some authors as heart-ripewood, by others only as sapwood; it has no true heartwood, at least the characters of a heart-ripewood are not marked. Color of the wood a characteristic reddish white. Annual ring boundaries narrow, dark streaks; in other parts of the ring the vessels are very uniformly distributed. The sharply demarcated, broad medullary rays with strongly satiny luster, in cross-section lighter, in longitudinal section darker than the surrounding wood, in radial section forming mostly short, dark, lustrous streaks which are characteristic of this wood.—Hard, easily split, very durable** under water, decays soon in the open, easily bent after steaming, —Valuable for water construction, street pavement, stairs, secondary railroad ties, water wheels; also employed in furniture and carriage building, for wine and beer casks, for agricultural implements; after staining, used for cigar boxes· not suited for tool handles, as it "burns" in the hand (EXNER).

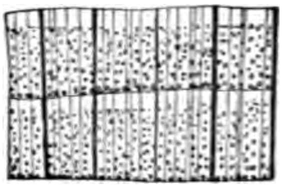


FIG. 151.

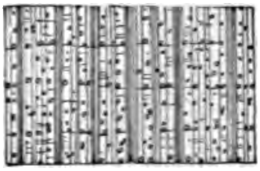


FIG. 152.

FIG. 151. Red Beech (*Fagus sylvatica*). Cross-section under Lens. (T. F. HANAUSEK.)

Diffuse-porous; the boundaries of annual rings narrow streaks without vascular bundles; medullary rays distinct.

FIG. 152. Hornbeam (*Carpinus betulus*). Cross-section under Lens. (T. F. HANAUSEK.)

Diffuse-porous; vessels not evident to naked eye; boundaries of rings narrow; cross-streaks of wood parenchyma; false medullary rays, broad, distinct.

82. *Carpinus Caroliniana* Walt. (=*C. Americana* Lam.), Hornbeam, Blue Beech, Ironwood. Central and eastern United States.—Entirely sapwood of a white color and close structure; other characters, also uses, same as of the following species.

83 *Carpinus betulus* L., Harst or Horst Beech, Yoke Elm (Fig. 152). Europe.—Sapwood yellowish white; annual rings often coarse, wavy; ring boundaries distinct but very narrow lines, in other respects the ring is uniformly dense and therefore the wood is very homogeneous. The broad, rather dull medullary rays are false, that is they resolve

themselves under a lens into several fine rays; these false rays of variable width, lighter than the surrounding wood. Sometimes delicate cross-streaks and light spots are present; these consist of wood parenchyma with thin-walled wood fibers.—Hard, heavy, hard to split, durable in dry places.—Used for machine parts, agricultural implements (flails, handles, etc.), felloes, pegs, household utensils; well suited for parts subjected to friction or pounding.

Wood hard; medullary rays lustrous.......................... 37

Wood soft; medullary rays dull.............................. 38

Wood light, yellowish white; medullary rays very strongly lustrous (in *Acer Pseudoplatanus* medullary rays distinct)..............*Acer*

Wood wine-red to red-brown (heartwood)..........*Prunus serotina*

Wood light; annual rings distinct; medullary rays fine, of different sizes, several rays invisible under lens between the visible ones.*Tilia*

Wood gray to brownish; annual rings indistinct............*Nyssa*

84. *Acer saccharinum* L., Sugar Maple, Hard Maple, Rock Maple. Central and eastern United States and southeastern Canada.—White, without dark heartwood; annual rings very uniform, with very delicate ring boundary; medullary rays visible only under lens, in radial section of somewhat uniform breadth.—Hard, fine, heavy, tough.—Much used for furniture, flooring, finishing woodwork, turned wares, shipbuilding, etc. Curly maple and especially bird's-eye maple are much prized for fine furniture and interior finish.

Other American species are: *A. rubrum* L. (Red or Swamp Maple), *A. macrophyllum* Pursh. (Broad-leaved Maple).

85. *Acer Pseudoplatanus* L., Sycamore Maple. Europe.—White or yellowish white, resembling birch in color, without heartwood. Annual rings uniform; ring boundaries fine, not wavy or only very slightly; medullary rays almost distinct, in radial section very numerous, high and short, strongly lustrous.—Hard heavy, tough, splits with difficulty, warps and cracks, durable in dry places.—A good wood for furniture, parquetry, inlaying, plates, bowls, spoons, shoe pegs, boxes, smoking-pipes, carvings, toys.

86. *Acer platanoides* L., Norway Maple, Plane Maple (Fig. 153). Europe.—Very similar to preceding, but the annual ring boundaries are not so fine and are always wavy, and the medullary rays are finer.—Less esteemed than preceding species, but used for same purposes.

87. *Acer campestre* L., Common Maple, Field Maple (Fig. 154). Europe.—Reddish white, not infrequently with pith flecks which are yellowish in reflected, and dark brown in transmitted, light; annual rings somewhat irregular; ring boundaries finely and coarsely wavy. In radial section very strongly lustrous; denser, heavier, and tougher than preceding.—Used for whip handles, garden chairs, toothpicks, imitations of other woods. Maple often has a beautiful grain; especially prized are American, Russian, and Hungarian bird's-eye maples (see *Acer saccharinum*).

88. *Tilia Americana* L., Bass Wood, American Linden, Lime Tree. Central and eastern North America —White with light-brownish cast; medullary rays unequally prominent; vessels not visible under lens, very numerous; boundaries of annual rings brownish lines.—Very soft, light, easily split.—Used for cheap furniture, carpenter work, panelling, toys, and various small articles.

89. *Tilia parvifolia* Ehrh., Small-leaved Linden, Winter Linden (Figs. 137 and 138). Europe.—Reddish-white ripewood; sapwood broad, white; annual rings partly uniform, partly not uniform; boundaries of rings mostly not wavy, disappearing somewhat inward; vessels in annual rings diffuse and much more numerous than in *Acer;* medullary rays not so distinct, very thick, only slightly or not at all lustrous.—Very soft, light, easily split, not durable, shrinks and warps but little, next to aspen the whitest wood.—Excellent wood for carving; valuable for concealed parts of furniture, hat forms, wooden shoes, and toys.

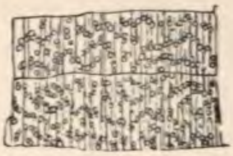


FIG. 153.

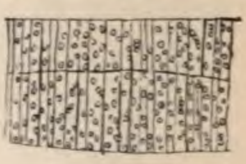


FIG. 154.

FIG. 153. Norway Maple (*Acer platanoides*). Cross-section under Lens. (T. F. HANAUSEK.)

Diffuse-porous; medullary rays recognizable under lens, some almost distinct; vessels here and there forming wavy lines; boundaries of rings wavy.

FIG. 154. Field Maple (*Acer campestre*). Cross-section under Lens. (T. F. HANAUSEK.)

Diffuse-porous; all medullary rays recognizable, very fine, uniformly developed, strongly lustrous; boundaries of rings narrow, broadly wavy; pith flecks present.

The wood of Summer Linden (*Tilia platyphyllos*) is scarcely distinguishable from the last.

90. *Nyssa sylvatica* Marsh. (=*N. multiflora* Waug.), Tupelo, Sour Gum, Black Gum, Pepperidge. Eastern United States.—Gray, yellowish gray to brownish gray, of fine texture. Medullary rays very delicate, in cross-section light, rather uniformly broad, closely arranged; annual rings very indistinct, in parts entirely disappearing, or not present at all (distinction from *Tilia*, *Acer*, and *Populus*).—Heavy, hard, very tough, splits with difficulty.—Used for wagon hubs, wooden utensils, handles, wooden shoes, pump pipes.

39. (33) Hard Woods 40
Soft Woods 47

0. Annual rings indistinct, or visible on magnification; wood yellow, strikingly mottled with black.................................*Olea*
Annual rings distinct, wood not mottled....................... 41

91. Olea Europea L., Olive Tree.—Heartwood beautiful yellow, mottled with brown to black; in longitudinal section characterized by peculiar dark waves; annual rings and medullary rays only evident with considerable magnification; pores regularly distributed, very small, in spring wood somewhat more crowded, therefore wood classed as ring-porous.—Very dense, almost homogeneous, extraordinarily hard, grain often very beautiful.—Objects of art, mosaics, and trinkets are made from olive wood in Vienna, Paris, Sorrento, and Belaggio; in Arco is a school for olive-wood industries.

. Wood commonly light yellow to reddish white................. 42
Wood always with dark heart; boundaries of annual rings dark lines (*Pomaceæ*).. 44
Wood brick-red; very curly grain; annual rings indistinctly evident. *Erica arborea*

92. Erica arborea L., Brier Wood (corruption of Bruyère). Spain, South Africa, and Corsica.—Wood of root brick-red, gradually becoming brown-red, in large part curly, very dense, heavy, not cleavable, difficultly combustible owing to high content of silica.—Highly prized for smoking-pipes.

2. Wood light yellow; annual rings mostly represented by delicate, dark lines; exceedingly hard and homogeneous, almost horny; the closest grained of all woods................................*Buxus*
Wood yellowish or reddish white; boundaries of annual rings light lines, not so fine as preceding.................................. 43

3. Wood yellowish white; vessels not evident with lens....*Evonymus*
Wood light reddish; medullary rays scarcely evident with lens; vessels not evident with lens; cross-section finely mottled by light-colored, rather broad, sinuous, radial streaks................*Ostrya*
Wood almost always reddish white; often with pith flecks; vessels evident with lens as light points..........................*Betula*

93. Buxus sempervirens L., Boxwood. Europe, the best from Black Sea (Abchasia).—Characterized by the color, density, and remarkable fineness of grain. Shows no details of structure even in longitudinal section; after planing the surface is entirely flat, homogeneous. Very heavy, splits with great difficulty, dull, durable.—Very valuable for woodcuts, wind instruments, fine turned wares.

94. Evonymus Europæa L., Spindle Wood, Skewer Wood. Europe.—Wood throughout yellowish white, uniform, very dense; annual rings represented by delicate light-colored lines; pores very small, rather crowded; yellow spots not infrequently visible on longitudinal sections.—Hard, splits with difficulty, easily cut, takes fine polish.—Adapted for turned wares, shoe pegs, toothpicks.

95. Ostrya Virginica Willd., Hop Hornbeam, Ironwood. Central and eastern North America.—Wood light reddish without dark heart; medullary rays scarcely visible under lens. Easily recognized by the light-colored, sinuous or bowed radial streaks, like those of oak, which give the wood a mottled appearance.—In other technical characters resembles *Carpinus Caroliniana* and used for same purposes.

96. Betula lenta L., Black Birch, Cherry Birch, Mahogany Birch. Central and eastern North America.—Light reddish, of fine structure; vessels easily recognized under lens, in thin section almost distinct, not very numerous; medullary rays very delicate and of uniform breadth, easily seen under lens. Boundaries of annual rings distinct, dark lines.—Hard, takes fine polish.—Often stained in imitation of mahogany. Much used for furniture, also for spools, boxes, wagon hubs, and ox yokes.

B. lutea Michx. (Yellow Birch) and *B. papyrifera* Marsh. (White Birch, Canoe Birch, Paper Birch) are used for similar purposes as *B. lenta.*

97. Betula alba L., European White Birch.—When young, white, later almost always reddish; consists entirely of sapwood. Annual rings distinct, mostly strongly wavy; boundaries of rings narrow, distinct lines. Vessels numerous, very closely arranged, of rather uniform size; medullary rays almost distinct under lens.—Heavy, hard, also sometimes almost soft, tough-fibrous, hard to split, not durable in open.—Valuable for carriage parts (felloes, poles, brakes, shafts), furniture, shoe pegs, frames of horse collars, brush backs, wooden shoes, spoons; curled specimens used for tobacco pipes. Swedish curled birch, known as Japanese nutmeg wood and characterized by its yellowish color and black-brown spots and streaks, is used for trinkets.

44.[1] Medullary rays in tangential section 1–4-rowed........... *Mespilus*
Medullary rays in tangential section 1–3-rowed; never 4-rowed, mostly 1–2 rowed. 45

98. Mespilus Germanica L., Medlar. Europe.—Distinguished from other pomes by the 1–4 rows of cells in medullary rays, which in addition are variable in shape and irregularly arranged.—Hard, heavy, in other respects much like white thorn.—Seldom used.

45. Vessels without tertiary thickened streaks...................... 46
Vessels with tertiary thickened streaks.............. *Sorbus* (*Aria*)

---

[1] The wood of the pomes can be distinguished with certainty only by microscopic investigation. The microscopic characters here given are after descriptions by BURGERSTEIN.

99. ***Sorbus Aria*** **Crantz (=*Aria nivea* Host.), White Beam Tree.**—Sapwood yellowish or reddish white; heartwood red-brown, sometimes brownish, mottled, with pith flecks. Boundaries of annual rings brown, in transmitted light distinct, lines, with a somewhat wavy course. Medullary rays very narrow and numerous, under lens straight rays also visible. Vessels very small, visible under lens only in thin section.—Microscopy: 9–12 medullary rays in 1 mm. of cross-section; breadth of vessels 38–50μ; medullary cells mostly 15–19μ high.—Hard, tough, hard to split.—Well adapted for machine parts, turned articles, instruments, moulds, and woodcuts; a substitute for maple.

100. ***Sorbus torminalis*** **Crantz, Service Tree.**—Very similar to preceding, but heartwood somewhat darker, medullary rays sharper. Vessels more numerous, somewhat larger, consequently wood less dense and less valuable.

46. No true heartwood, heart mostly decayed wood, wood often brownish red throughout; 12–16 medullary rays in 1 mm. of the cross-section; height of medullary rays 13–15μ .... *Pirus*
True heartwood; heart dark red-brown; 10–13 medullary rays in 1 mm. of cross-section; height of medullary rays 13–17μ.... *Malus*

101. ***Pirus communis*** **L., Pear.**—Reddish brown, sometimes varying to dark brown; heart rotten; sapwood passes into ripewood. Boundaries of annual rings distinct, sometimes very narrow, brown lines. Very dense and uniform, medullary rays under lens very delicate.—Rather hard, splits with difficulty, durable in dry places.—Excellent for turning and carving, printing-blocks, tools, planes, wood screws; the ebonized wood much used for fine furniture.

102. ***Malus communis*** **L. (*Pirus Malus* L.), Apple.**—Sapwood light brown; heartwood dark red-brown (especially striking in transmitted light). Annual rings of different breadth, vessels sometimes grouped so as to form zones, even on the spring wood boundaries (which is never true of pear wood). Rather hard, splits with difficulty, not durable.—Like the last species, used for toys, carved trinkets, spigots, pipe stems, but is less valuable.

47. (39) A strikingly colored heartwood always present (*Salicaceæ*).. 48
Wood uniformly colored without strikingly colored heartwood, yellowish white (like ivory), rarely somewhat reddish. ..... *Æsculus*
Wood dirty white, with characters of *Salicaceæ* but without heartwood .... *Populus tremula* and *P. tremuloides*

103. ***Æsculus Hippocastanum*** **L., Horse-chestnut.**—Sapwood fine-grained, white; boundaries of annual rings distinct light lines; annual rings somewhat uniform; medullary rays (in tangential section) one-rowed.—

Soft, easily split, of very uniform structure, not durable.—Used for casks, wooden shoes, marquetry.

104. *Æsculus glabra* Willd., Ohio Buckeye. Central United States.—Used for wooden utensils, artificial limbs, paper manufacture, and also for building.

Æsculus flava Ait., Sweet Buckeye, is also used for the purposes named.

105. *Populus tremuloides* Michx., Aspen, Quaking Asp. Northern United States and British America, from Atlantic to Pacific.—Very similar to following species. Annual rings distinct.—White, soft, light.—Used for same purposes as No. *109*.

106. *Populus tremula* L., Aspen, Trembling Poplar. Europe.—Annual rings distinct; medullary rays easily seen under lens; no marked characteristics.—Light, very soft, splits easily and with beautiful fracture, not durable, becomes reddish with age.—A valuable wood for Swedish matches, planks, boards, shingles, casks, boxes, piles, sheathing of railroad cars, basket work (in thin splinters); one of the most important woods for paper pulp.

48. Sapwood reddish white; heartwood light red..........*Salix caprea*
Sapwood white; heartwood dark brown....*Salix alba*, *S. fragilis*, etc.
Sapwood white; heartwood yellow or light yellow-brown
Populus deltoidea, *grandidentata*, *alba*, *nigra*, etc.

107. *Salix caprea* L., Sallow, Goat-willow. Europe.—Sapwood white or yellowish white; ripewood reddish; heartwood light red to light brownish red; annual rings mostly broad, spongy because of numerous vessels, in longitudinal section very lustrous; medullary rays uncommonly delicate and numerous.—Soft, very light, splits easily.—Used for coarse matwork, fascines, grape-vine stakes, and paper pulp.

108. *Salix alba* L., White Willow, and *Salix fragilis* L., Brittle Willow, Crack Willow. Europe.—Distinguished from last by the decidedly dark heartwood; used for same purposes.

109. *Populus deltoidea* Marsh. (=*P. Canadensis* Moench., *P. monilifera* Ait.), Cottonwood. Abundant in river valleys from Appalachian to Rocky Mountains.—Sapwood yellowish white; heartwood dark brown; boundaries of annual rings delicate but distinct lines. Spring wood with numerous vessels of almost uniform size, often radially arranged; summer wood with few vessels, not visible under lens, therefore wood quite compact. Medullary rays visible under lens only in boundaries of annual rings, very narrow and everywhere of uniform size.—Silky lustrous, very light and soft.—"Used as building and furniture lumber, in cooperage, for sugar and flour barrels, for crates and boxes, for wooden ware and paper pulp" (ROTH).

110. *Populus grandidentata* Michx. Poplar. Northern United States to Minnesota, Canada, Alleghanies.—Heartwood light brown, somewhat heavier than preceding, but used for same purposes

Similar species are *P. Fremontii* Wats. (Cottonwood) of California and southwestern United States and *P. trichocarpa* Torr. et Gray (Black Cottonwood, Balsam Cottonwood) of western British America and the Pacific States.

111. ***Populus alba*** L., White Poplar, Abele, Abeltree, and *P.* ***nigra***, Black Poplar. Europe.—Sapwood white; heartwood yellow (*P. alba*) or light brownish (*P. nigra*), soft and light. See No. *106* for uses.

49. (15) Gives with alkalies definite color reactions..........Dyewoods (See Yellow Woods, p. 244; Blue Woods, p. 251; and Red Woods, p. 252. The curled woods of ***Pterocarpus Indicus***, ***saxatilis***, etc., under the name of Amboyna wood, are used for pipes and veneering.)
Used only for woodworking (tropical ornamental woods [1]). 50
50. In cross-section appear structureless to naked eye.............. 51
In cross-section either pores, or pores and medullary rays, or else striking cross-streaks visible to naked eye.................... 52
51. Heartwood black ....Ebony
Heartwood brown red with spotted markings..........Snake-wood
Heartwood yellow red with dark or black stripes (not spotted). Cocobola
Wood white, very fragrant.....................White Sandalwood

112. Ebony, ***Diospyros Ebenum*** König, and other species of ***Diospyros***.[2]—Sapwood white, thin; heartwood deep black; pores diffuse, radially arranged in twos and threes; medullary rays in one row, containing crystals—Commercial varieties: Macassar, Zanzibar, Mauritius, Ceylon, and Siam. Exceedingly hard and heavy, homogeneous, the best sorts without cracks, curls, or light streaks; white-spotted varieties, however are also highly prized

113. Colored or Streaked Ebony, Calamander Wood, Coromandel Wood, from ***Diospyros hirsuta*** L. fil.—Coffee-brown, not uniformly colored; medullary rays often in two rows.

114. Orange River Ebony, from ***Euclea pseudebenus*** E. Mey., is very similar to true ebony.

115 Snake-wood, Itaka Wood, also known as Nutmeg-, Letter-, Leopard- and Tiger-wood, from the American species ***Piratinera Guayanensis*** Aubl. (or from ***Machærium Schomburgkii*** Benth.).—Heartwood brown-red with characteristic dark stripes and spots.—Exceedingly hard and heavy and very expensive. See also No. *134*.

---

[1] For exhaustive descriptions of physical and microscopic characters, see WILHELM in Wiesner's Rohstoffe. 2. Aufl. 1903, **2**.

[2] MOLISCH: Vergleichende Anatomie des Holzes der Ebenaceen und ihrer Verwandten. Sitzb. Wien. Akad. 1879, **86**, I, 78.

116. **Cocobola. Species uncertain. Central America.—Bright yellow-red becoming darker with time; in cross-section with dark or black zones resembling annual rings corresponding to stripes seen in longitudinal section; medullary rays not visible under lens; vessels rather large, few, isolated, often surrounded by a light border, filled with a beautifully lustrous red mass.—Very hard, dense, and heavy, hard to work.—Much used for knife and tool handles and brush backs.**

117 **White Sandalwood. *Santalum album* L. Light yellow brown, mostly with concentric rings containing coloring matter and resembling annual rings; vessels detached, filled with yellow resin; medullary rays 2-4-rowed (in tangential section). Delightfully fragrant.—Macassar sandalwood is very similar to the last.**

52. Pores visible, medullary rays invisible under lens.............. 53
Pores and medullary rays visible to naked eye................ 56
Wood in cross-section distinctly cross-streaked................ 57

53. Wood with striking and characteristic odor.................... 54
Wood without characteristic odor............................ 55

54. With violet odor....................................Violet Wood
With resinous odor; resin exudes on warming.........Lignum-vitæ

118. Violet Wood, Myall, *Acacia homalophylla* Cunn. Australia.—Heartwood chocolate-brown to olive-green. Exceedingly hard and heavy, does not split, characterized by violet odor.—Used for tobacco pipes and trinkets.

119. Lignum-vitæ, *Guajacum officinale* L. Tropical America.—Heartwood greenish or brownish black. Exceedingly hard and heavy, does not split, highly durable.—The best wood for ships' pulleys, bowling-balls, and certain parts of machines.

55. Wood flesh-red and carmine-red, banded and mottled....Tulip Wood
Wood with dark stripes on cinnamon or fox-colored ground.
Zebra Wood
Wood brown with numerous sulphur-yellow dots (pores)..Greenheart

120. Tulip Wood, Brazilian Rosewood (*Physocalymna scaberrimum* Pohl). Brazil.—Characterized by the light- and dark-red markings; without odor. Other varieties known on the Continent as "rosewood", characterized by the red color, but without a rose odor, are West Indian, African, Queensland Rosewood, *Bois de Chypre* (*Cordia*, *Dalbergia*, *Cæsalpinia*, etc.).—Odorous varieties are obtained from *Amyris* and *Convolvulus*.

121. Zebra Wood (*Centrolobium robustum* Mart.). South America.—A moderately soft, ornamental wood, valuable for veneers.

122. Greenheart (*Nectandra Rodiæi* Hook.). Guiana.—Somewhat similar to lignum-vitæ, except that the color is yellow-brown, and used for same purposes. Cogwood (*Ceanothus Chloroxylon* Nées) is also similar.

56. Wood brown, uniform................Mahogany, Cailcedra Wood
Wood yellowish green and deep brown in layers...Green Havana Wood
Wood yellow, similar to true boxwood...........Tropical Boxwoods
Wood cream color or yellowish, splits with difficulty, silky lustrous.....................................Primavera Wood

123. Mahogany, *Swietenia Mahagoni* and other species. Tropical America.—Beautiful brown, moderately hard and heavy. Splits with difficulty. The wood on the market is usually classed as true, Spanish, or Santo Domingo Mahogany and Honduras Mahogany or Baywood, the former having the more beautiful grain. The following designations are also current: Cuba, Jamaica, Hayti, Yucatan, Laguna, Porto Plata, and Tabasco.

124. Cailcedra Wood, *Khaya Senegalensis*, is somewhat similar to last, but more of a red-brown color. Other species resembling mahogany are Arena Mahogany from Chile, Bastard or Colonial Mahogany (species of *Eucalyptus*), and Cape Mahogany, *Ptæroxylon*, etc. The last species is characterized by the beautiful golden shimmer of the polished wood.

125. Green Havana Wood, *Tecoma leucoxylon* Mart.—Valuable because of its beautiful markings.

126. West Indian Boxwood (*Aspidosperma*) and

127. Australian Boxwood (*Pittosporum*) are both yellow woods used as substitutes for true (Turkish) boxwood.

128. Primavera Wood from Central America is yellowish, moderately hard.—Much prized for veneers.

57. Brownish violet with black veins........................Rosewood
Dark brown-red or dark flesh color........................Beefwood
Violet...King Wood
Coffee-brown to olive green.................Grenadilla Wood, etc.

129. Rosewood, Palisander, *Jacaranda Brasiliana* Pers. (?). Tropical America.—Several varieties are on the market, the most valuable being Rio and Bahia.—In longitudinal section deep brown with irregular black streaks and coarse furrows. Very heavy and hard, strongly resinified, fragrant.—One of the most valuable wood for veneers, fine furniture, handles, etc.

130. Beefwood, Bully Tree, *Bois de perdrix*, *Pferdefleischholz*, *Swarzia tomentosa* DC., or possibly *Mimusops Balata* Gaert. Tropical America.—Exceedingly hard and heavy.—Used chiefly for fiddle bows.

131. King Wood, Violet Wood. Madagascar.—Heartwood violet with dark zones, very distinctly interrupted and cross-streaked; often purple-black.

132. Grenadilla or Granadilla Wood. This name is applied to several woods. True Granadilla Wood or American Green Ebony (*Brya ebenus* DC.) is coffee-brown with violet tint, also almost ebony-black.—Used for wind instruments.

African Granadilla Wood is from *Dalbergia melanoxylon* Guill. et Pers.

133. Cocus Wood, Cuba Granadilla Wood, *Inga vera* Willd. (incorrectly known in some European markets as cocos wood). West Indies and Central America.—Heartwood dark olive-green to black.—One of the most valuable woods for turned articles, such as tobacco pipes, handles, clarinets.

134. Partridge Wood, Pheasant Wood, *Andira inermis* H.B.K., and Vacapou or Wacapou Wood, Brazilian Teakwood, *A. Aubletii.* South America. —Dark brown, in longitudinal section suggesting palm wood, marked with fine light and dark stripes similar to the features of the partridge. Resembles No. *115.* Exceedingly hard and heavy, very durable.

Rare Woods.

135. Red Wood, Condori Wood, Coral Wood, *Adenanthera pavonina* L. India (native), Tropical America (cultivated).—Light reddish brown, hard, heavy.—Used for fine furniture.

136. Padouk, East Indian Mahogany. *Pterocarpus Indicus* Willd. (?). West Africa.—Similar to African sandalwood (see Red Woods).—Used for furniture, ornamental woodwork, and brush backs.

137. West Indian Satinwood, *Fagara flava* Krug et Urb.—Yellowish with light and dark zones; in longitudinal section with light and dark stripes and beautiful satiny luster.—Employed for furniture, turned articles, and inlaying.

138. East Indian Satinwood, *Chloroxylon Swietenia* DC. Further India and Ceylon.—Similar to last, but heavier.

139. Barsino Wood. Brazil.—Very hard and heavy, brown with brown-black cross-zones.—For canes, brush backs, etc.

140. Zirikota Wood. Species unknown. Mexico.—Characterized by peculiar and beautiful markings.—Medullary rays prominent in longitudinal section as light-brown, transverse scales, crossed by light-colored scratches (vessels) in a dark ground tissue.

141. Purple Heart, Purple Wood, *Copaifera bracteata* Benth. South America. —Brown, soon becoming a beautiful red. Pores, especially on the outer side, accompanied by parenchyma.—A beautiful ornamental wood.

142. Tambinziran Wood, Red Havana Wood. Species of *Leguminosæ.*— Uniformly red-brown, moderately hard and heavy.

143. Algaroba Wood, *Hymenæa Courbaril* Link.—Brown-red, very hard and heavy.—For turned articles.

144. Agallochium,[1] Agal Wood, Eagle Wood, Lign-aloes, Calambac. The

---

[1] Moeller: Lignum Aloës und Linaloëholz. Pharm. Post. 1897, **30**, 531. *Idem:* Lignum Aloës. *Ibid.* 1898, **31**, 545.

genuine is of two kinds, one from species of *Aquilaria*, the other from *Gonostylus*.—Rich in resin, fragrant.—Used in pharmacy.
Substitutes for the last are woods from species of *Bursera*, natives of Mexico, and "Likari" or "bois de rose femelle", probably *Ocotea caudata* Mez., from French Guiana.

58. (14) Stem hollow.................................... Bamboo
Stem solid......................................Palm Woods

145. Bamboo, *Bambusa arundinacea* L.—Knotty-jointed, smooth and lustrous on outer surface, hollow, up to 15 meters high.—An important building material in the Orient. Used also for furniture, walking-sticks, fishing-rods, trinkets, etc.

146. Palm Wood, Palmyra Wood, Zebra Wood.—Dark threads in a ground tissue (usually brown). White palm wood (date palm, cocoanut palm) is distinguished by its color from black palm wood (Palmyra palm, Gomuti palm).

147. Rattan, species of *Calamus* (see p. 255).

D. Dyewoods.[1]

Dyewoods, notwithstanding the coal-tar colors, are still of great importance in the dyeing industry and are of special value in producing the so-called new or fashionable colors, various shades of gray and brown, fast blacks, etc. With the exception of fustic and barberry, they are from non-European trees and usually are from the trunks of tropical heartwood trees. They are shipped in the form of blocks, sticks, or chips and are reduced to the proper mechanical condition in establishments devoted entirely to this work. The wood is commonly cut across the grain, rasped, or ground, the product being variously designated as sawdust, shavings, needles, etc. Usually the material is subjected to a fermentation process in heaps piled in dark, well-ventilated lofts, the heaps being repeatedly moistened and shovelled over and finally allowed to stand several weeks. In this way, as those in the trade say, the partially formed dye is completely developed and the amount is augmented. As a matter of fact, the fermented wood has a much greater tinctorial power than the unfermented. The coloring principle is either ready formed in the wood, in which case it may be free or combined as a glucoside or a salt, or else the chromogen is present, which under the influence of light and other unknown factors is converted into the dye. Doubtless the fermentation acts to bring about these changes.

---

[1] BENEDIKT: Realenzyklopädie d. ges. Pharm. 2. Aufl. 1905, **5**, 180. v. HÖHNEL: Beiträge zur technischen Rohstofflehre. Dingler's Polyt. Jour. 1880, **235**, 74–79. MOELLER: Beiträge zur vergl. Anatomie des Holzes. Denkschr. Wien. Akad. 1876, **36**. *Idem:* Die Rohstoffe des Tischler- und Drechslergewerbes. Holz. 1883, **1**. TSCHIRCH: Realenzyklopädie d. ges. Pharm. 2. Aufl. 1905, **5**, 185. VOGL: Untersuchungen über den Bau und das mikrochemische Verhalten der wichtigsten Farbhölzer des Handels. Lotos, Märzheft, 1873.

The coloring matter of commercial dyewoods impregnates the walls of all the tissue elements; it also occurs in the parenchyma cells and the vessels in the form of resinous drops or hard formless lumps accompanying starch grains, oxalate crystals, etc. Formerly the coloring matter was regarded as formed by a chemical metamorphosis of the middle lamella, since in the heartwood, the walls of which are colored throughout, the middle lamella contains a larger amount of coloring matter than the other layers, and in the sapwood the middle lamella is colored while the other layers are colorless. At the present time, however, the coloring matter is believed to be formed in the cell contents and absorbed by the cell membranes, lignified membranes being especially adapted for the absorption of infiltrated substances.

Dyewoods are grouped under three heads according as they are colored yellow, blue, or red.

YELLOW WOODS.

The common yellow woods are old fustic, young fustic, and barberry.

OLD FUSTIC.[1]

Old fustic, or common yellow wood, is the heartwood of ***Chlorophora tinctoria*** (L.) Gaudich. (=*Maclura tinctoria* Don.=***Morus tinctoria*** Sacq.=*Broussonetia tinctoria* Kth., order *Moraceæ*), a tree growing in Central and South America. The commercial product, designated, according to the place of production, as Cuba, Porto Rico, Domingo, Carthagena, Maracaibo, Tabasco, and Tampico, consists either of large pieces of wood from the trunk and branches or of chips largely freed from the sapwood.

The wood is somewhat heavy and hard, easily split, and usually of a dirty lemon-yellow color. On standing it darkens, pieces an inch thick becoming a brown color throughout. Cross-sections show brownish concentric markings of various breadths, but no true annual rings; also very numerous wavy yellow lines in a ground tissue of the same color. Very fine medullary rays are evident to the naked eye in places which have been polished and moistened. Radial cleavage surfaces are fibrous-knotty, strongly greasy or silky lustrous, occasionally with golden-yellow spots or longitudinal streaks. Freshly cut surfaces treated with potash or ammonia become orange-yellow; pieces warmed with hydrochloric acid become dark violet (maclurin reaction). Under a lens numerous fine medullary rays of various breadths are evident, also in a brown ground mass tangentially arranged, partly continuous and partly interrupted, lemon-yellow wavy lines with somewhat pointed sinuosities in which occasional pores (open vessels), thick circular specks (vessels stopped with tyloses), and clear, shining spots are evident (Fig. 155).

---

[1] T. F. HANAUSEK: Ueber die wichtigsten Unterscheidungsmerkmale des echten Gelbholzes Fustik und des ungarischen Gelb- oder Fisetholzes. Chem. Ztg. 1886, **10**, 1586. *Idem:* Realenzyklopädie d. ges. Pharm. 2. Aufl. 1905, **5**, 463.

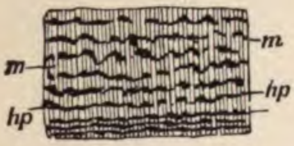


Fig. 155.

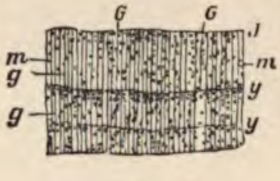


Fig. 156.

Fig. 155. Old Fustic. Cross-section under Lens. (T. F. Hanausek.)
m medullary rays; *hp* wood parenchyma.

Fig. 156. Young Fustic. Cross-section under Lens. (T. F. Hanausek.)
G spring vessels; *g* summer vessels; *m* medullary rays; *J* and *y* boundaries of annual rings.

Microscopic examination of cross-sections shows thick, almost golden-yellow masses of libriform cells (Fig. 157) interrupted by bands of wood parenchyma (*hp*) of various breadths, some of which are forked. Usually the vessels (*g*) occur singly or in groups of 2–4. They have thick walls with bordered pits and are for the most part stopped by tyloses which also here and there have pitted walls. The wood parenchyma consists of axially elongated thin-walled parenchyma cells with simple pits, often filled with simple, globular starch grains, 10–14μ in diameter, accompanied by chambered fiber cells, each chamber containing a beautiful hendecahedral crystal of calcium oxalate. The medullary rays are 1–4 cells broad and up to 12 cells high; the walls of the medullary cells have simple pits. The libriform fibers are only slightly thickened (Figs. 159 and 160).

According to A. Vogl, the cracks of Cuban fustic contain yellow masses consisting chiefly of two forms of crystals which may be the two coloring substances. Formerly only one coloring substance,[1] **Morin** ($C_{13}H_{10}O_6$), had been definitely isolated. "This exists in the wood partly combined with lime and may be separated by boiling with hydrochloric acid. By recrystallizing the precipitate from alcohol the substance is obtained in yellow scales. . . . In addition to morin, which is nearly insoluble in boiling water, fustic also contains an easily soluble coloring substance only recently isolated, also **Maclurin**, an isomer of morin, which has not the properties of a dye" (BENEDIKT). Yellow, brown, and olive-green colors are secured by dying with fustic.

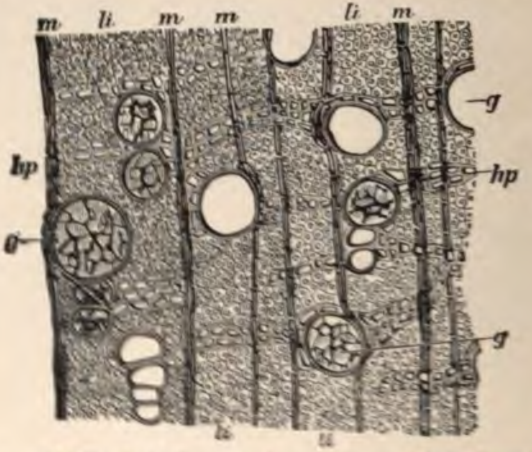


FIG. 157. Old Fustic in Cross-section. ×300. (T. F. HANAUSEK.)
g vessels, closed by tyloses; *m* medullary rays; *li* libriform fibers; *hp* wood parenchyma.

YOUNG FUSTIC.[2]

Young fustic, or Hungarian yellow wood, is the heartwood of the Venetian sumac (*Cotinus Coggygria* Scop. = *Rhus Cotinus* L., order *Anacardiaceæ*), growing in dry regions about the Mediterranean, also in Savoy, southern Tyrol (to Vienna), southern Germany, and Servia. The leaves of the same tree are used in the tanning industry. Fustic comes into the market in sticks of various sizes up to 12 cm. in diameter. The heartwood is surrounded by a thin white sapwood and shows in cross-section distinct annual rings consisting of dirty canary-yellow or yellow-green layers alternating with dark-brown zones. It has a strong silky luster, is somewhat homogeneous in structure, moderately hard, easily and evenly cleavable. On application of potash solution the wood becomes carmine to blood-red, changing to red-lead color on drying. After washing out the potash with water and treating with hydrochloric acid, the original yellow color is restored. Ammonia water or concentrated sulphuric acid gives a brown-red color, hydrochloric acid, without warming, vermilion spots.

---

[1] See BENEDIKT: Realencyklopädie d. ges. Pharm. 2. Aufl., 4, 252. Jul. Löwe: Ueber Morin, Maclurin und Moringerbsäure. Ztschr. Analyt. Chem. 1875, 14, 117.

[2] T. F. HANAUSEK: Chem. Ztg. 1886, 10, 1586. *Dieser*: Realencyklopädie d. ges. Pharm. 2. Aufl., 4, 370.

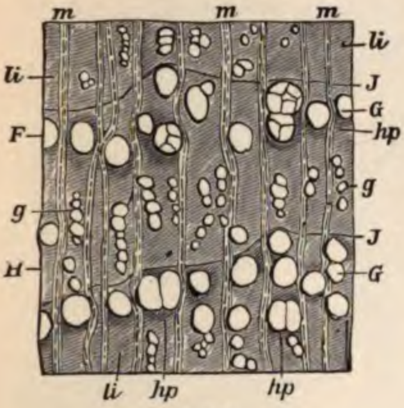


FIG. 158.

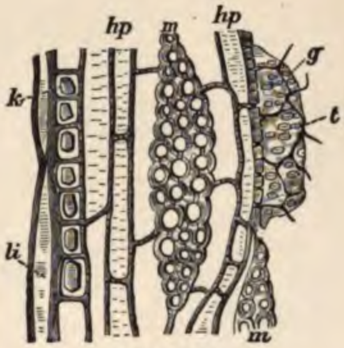


FIG. 159.

FIG. 158. Young Fustic. Cross-section, Semi-diagrammatic. (T. F. HANAUSEK.) *G* vessels of spring wood; *g* vessels of summer wood; *hp* wood parenchyma; *m* medullary rays; *li* libriform fibers; *J* boundaries of annual rings; *F* spring wood; *H* summer wood.

FIG. 159. Old Fustic. Portion of a Tangential Section. ×400. (T. F. HANAUSEK.) *m* medullary rays; *li* libriform fibers; *hp* wood parenchyma; *g* vessels with *t* tyloses; *k* oxalate crystals.

The spring wood (Fig. 156) begins with a delicate, sometimes well-marked, light line and contains numerous pores which are somewhat larger than those of the summer wood; the wood then is ring-porous (see analytical key, p. 229). Small pore streaks extend from the spring wood in radial or diagonal-radial rows into the summer wood. The medullary rays are very fine, nearly uniform in breadth throughout, scarcely lighter than the ground mass.

In the spring wood the vessels, which are 80–152μ broad and are filled with tyloses (Figs. 158, 161, and 162), occur singly or in pairs; in the summer wood the vessels, or more correctly the tracheids, occur

2–8 together in simple radial rows.[1] The walls of the large vessels have numerous bordered pits, those of the small vessels pits and a single or double spiral band. The bulk of the woody tissues consists of spirally thickened, pitted tracheids (with double spiral band) and rather broad substitute fibers (either smooth or with simple pits), together with occasional slightly thickened smooth libriform fibers. Wood parenchyma (Figs. 161 and 162, *hp*) is sparingly present. The medullary rays consist of one or two layers, very seldom of three layers. Orange-yellow to brown grains, which dissolve very easily in hot glycerine and alcohol to a yellow solution, occur in the cells of the medullary rays and the wood parenchyma. The walls of all the tissue elements, as well as their contents, become blood-red in alkalies, brown-red in concentrated sulphuric acid

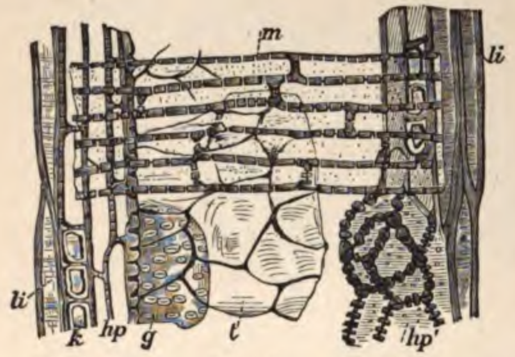


FIG. 160.

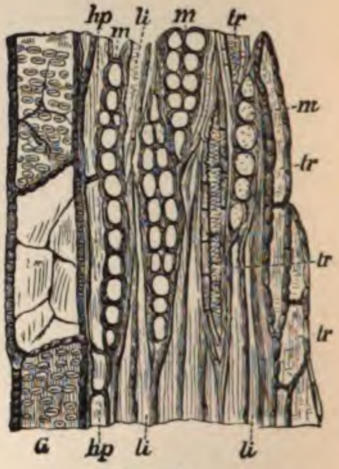


FIG. 161.

FIG. 160. Old Fustic. Portion of a Radial Section. ×400. (T. F. HANAUSEK.)
Significance of *m*, *li*, *hp*, *g*, *t*, and *k* as in Fig. 159; *hp'* irregularly developed wood parenchyma.

FIG. 161. Young Fustic. Tangential Section. (T. F. HANAUSEK.)
G large vessel; *m* medullary rays; *tr* short tracheids and wood parenchyma; *li* libriform fibers.

---

[1] Other authors also designate them tracheids. A. VOGL (Untersuchungen über den Bau, etc., p. 16 of the reprint) describes the tissue as follows: "The ground mass of the wood bundle consists of rather thick-walled substitute fibers (0.20 mm. in diameter and 0.4–0.7 mm. long) either smooth or with double spiral bands, and also of tracheids with spiral and slit-like pits. In this ground mass are very numerous broad spiral vessels (mostly 0.13–0.22 mm. in diameter) filled with tyloses, accompanied by wood parenchyma, and united on the sides with wood parenchyma layers."

and in Millon's reagent, dirty green to greenish-brown in ferric chloride, dark yellow in nitric acid, and vermilion in hydrochloric acid.

The coloring principle of young fustic is **Fisetin** ($C_{23}H_{16}O_9$), which occurs combined with tannic acid as a glycoside.[1] It crystallizes from alcohol in fine lemon-yellow needles, is easily soluble in alcohol, but almost insoluble in water.

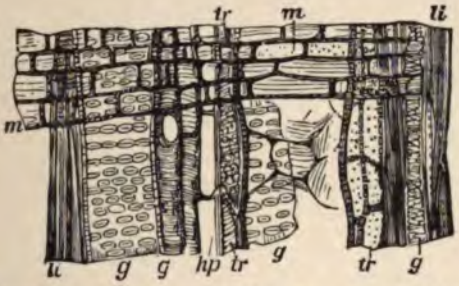


FIG. 162. Young Fustic. Radial Section. (T. F. HANAUSEK.)
g large vessels, with bordered pits, and small spirally thickened vessels; *hp* wood parenchyma; significance of other letters as in Fig. 161.

Young fustic serves as a yellow dye for leather and for the preparation of mixed colors, especially warm bronze and tan colors for wool.

DISTINCTION OF OLD FUSTIC FROM YOUNG FUSTIC.

In order to make the distinction between the two fustics clearer and to facilitate their identification the chief diagnostic characters are given below in parallel columns.

OLD FUSTIC.	YOUNG FUSTIC.
Macroscopic Characters.—Yellow, becoming brown on standing. In cross-section brownish circles of different breadth (but no real annual rings) and wavy lines in a brownish ground mass; very fine medullary rays evident to the naked eye, almost distinct or very easily distinguishable. Radial sections almost silky lustrous with golden-yellow spots and streaks.	**Macroscopic Characters.**—Yellow or green, darkening little on standing. In cross-section distinct annual rings (ring-porous wood), no wavy lines; medullary rays not evident to the naked eye, hardly distinguishable, or indistinguishable. All sections with a brilliant silky luster.
Reactions.—Moistened with potash or ammonia, orange-yellow; warmed with hydrochloric acid, dark violet.	**Reactions.**—Moistened with potash, carmine to blood-red (red-lead color on drying); with ammonia (and also sulphuric acid) brown-red; with hydrochloric acid, in the cold, vermilion.

---

[1] J. SCHMID: Wasserlösliches Fustintannid. Ber. Deutsch. Chem. Gesell. 1886, No. 11.

Blue Woods.[1]

LOGWOOD.

Logwood, or **Campeachy Wood,** is the very hard, heavy, rather easily cleavable heartwood of *Hæmatoxylon campecheanum* L. (order *Leguminosæ Cæsalpinioideæ*). The best grades come from the west coast of Yucatan and from Honduras, an inferior grade from the Antilles. The staple varieties are Domingo, Laguna, and Campeachy; " English logwood " onsists of blocks with ends sawed off at right angles, "Spanish logwood", f sticks with blunt-pointed ends. On standing in the air the wood ecomes violet to blackish, often with a metallic changeable efflorescence.

Light and dark zones, also orange-yellow, tangentially arranged bands id vessels in a dark ground mass, can be seen in cross-section with the iked eye. The medullary rays are evident. The vessels have bordered ts and are mostly in groups of 2–4. Libriform cells with strongly ickened, knotty, twisted fiber cells form the bulk of the ground mass. ood parenchyma elements occur in abundance. The medullary rays e 2–4 cells broad and up to 40 cells high.

Numerous brown masses occur in the vessels of Domingo logwood, it only a few in the wood parenchyma and medullary rays. The corsponding tissues of Laguna logwood are also rich in contents. The omingo product normally has a small amount of sapwood adhering.

Potash dissolves completely the pigment to a beautiful violet solution. ydrochloric acid imparts a carmine-red, Millon's reagent, a blood-red lor.

The dyeing properties of logwood are due to **Hæmatoxylin** ($C_{16}H_{14}O_6$), hich, however, is not a dye but a chromogen. Compounds of hæmaoxylin with bases (e.g., ammonia) rapidly absorb oxygen, thus forming he true dye **Hæmateïn.** For this reason logwood chips must be subjected to fermentation before they are ready for use. Logwood is chiefly used for black colors.

---

[1] Schacht: Der Baum. Berlin, 1853, 209. Vogl: Lotos, 11, and Commentar z. Österr. Pharm. 1892, 305. Wiesner: Rohstoffe. 1. Aufl. 1873.

RED WOODS.[1]

Red woods, of which a great number are known, differ greatly as to their value for dyeing. So far as their chemical constitution has been studied they contain only chromogens, either **Brasilin** ($C_{16}H_{14}O_5$), which is changed by oxidation in the presence of alkalies to **Brasileīn**, or **Santalin** which, according to WEIDEL, GANSWINDT, and others, is closely related to brasilin and brasileīn.

The most important red woods are:

1. **Pernambuco** or **Genuine Brazil Wood**, the heartwood of *Cæsalpinia echinata* Lam., from Brazil.
2. **Lima Wood** from *Cæsalpinia crista* L. (?).
3. **Nicaragua Wood** from *Cæsalpinia Brasiliensis* L. (?).
4. **Red Wood** from *Cæsalpinia tinctoria* Benth. (=*Coulteria tinctoria* H. B. K.) of Chile.
5. **Sappini** or **Bukkum Wood**, a false sandalwood from *Cæsalpinia Sappan* L. of the East Indies.
6. **Red Sandalwood,** or **Red Saunders,** from *Pterocarpus santalinus* L. of the East Indies.
7. **Camwood,** or **African Red Wood,** from *Baphia nitida* Afzel., *B. pubescens* Hook. f. and other species of *Baphia.*
8. **Barwood,** or **African Sandalwood,** from *Pterocarpus santalinoides* L'Hér.

---

[1] The extensive literature on red woods should be thoroughly overhauled and the statements made therein carefully corroborated. The most important articles are the following: C. BRICK: Beitrag zur Kenntniss und Unterscheidung einiger Rothhölzer, insbesondere derjenigen von *Baphia nitida* Afz., *Pterocarpus santalinoides* L'Hér. und *Pt. santalinus* L. Jahrb. Hamburg. Wiss. Anst. **6**, 1889. FLÜCKIGER: Pharmakognosie des Pflanzenreiches. Berlin, 1883, 405. V. HÖHNEL: Beiträge zur technischen Rohstofflehre, 1880, 78. TH. JAENSCH: Zur Anatomie einiger Leguminosenhölzer. Ber. Deutsch. Bot. Gesell. 1884, **2**, 270. W. KRAH: Ueber die Vertheilung der parenchymatischen Elemente im Xylem und Phloem der dicotylen Laubbaume. Berlin, 1883. MOELLER: Beiträge zur vergl. Anatomie des Holzes, 1876, 100, 415. E. PRAËL: Vergleichende Untersuchungen über Schutz- und Kernholz der Laubbaume. Pringsheim's Jahrb. Wiss. Bot. 1888, **19**, 1. R. SADEBECK: Die Kulturgewächse der deutschen Kolonien und ihre Erzeugnisse. Jena, 1899, 324-326. [illegible] OESTERLE: Anatomischer Atlas. Table 27 (*Lignum Santali* and *Lign.* [illegible], 113; 114. VOGL: Untersuchungen über den Bau, etc. Lotos, 1873, 56 (1-11 [illegible] Commentar z. Österr. Pharm. Wien, 1892, 304. WIESNER: [illegible] Pflanzenreiches

E. Cork Woods.

A small number of woods are characterized by their low specific ravity which enables the living tree to float on the water. Some of these oods serve as a substitute for cork, but only to a limited extent, since ie high elasticity, impermeability, durability (i.e., resistance of decomsition), so characteristic of cork, are not possessed at all by cork woods. ost of these woods belong to the order *Leguminosæ*, suborder *Papilnacæ*, some to the order *Bombaceæ*.

Among the cork woods are: *Ochroma Lagopus*,[1] *Æschynomene aspera* illd. (East Indies),[2] *Nyssa aquatica* L. (Tupelo wood of North America),[3] *rythrina acanthocarpa*, E. M.[4] The last named, a native of South frica, has enormous roots which come into market under the name of Kaffir Marble Cork" in blocks 2 m. long and 1 m. in circumference. t is brownish white, three times lighter than cork, but has little elasticity nd is permeable to liquids. Cross-sections show concentric lines conisting of narrow bands of 2–4 layers of parenchyma cells. The medullary ays are distinct, very thin, up to 5 cells thick. The bulk of the wood onsists of both radially and axially elongated cells with broad lumens, in walls, and numerous pits.

" Aloe wood," consisting of the pith of species of *Agave* and *Four-oya*, is also used as a substitute for cork.

It is obvious that the anatomical structure of cork woods is very different om that of heavy woods. The wood of *Herminiera Elaphroxylon* Guill. Perr. (=*Ædemone mirabilis* Kotschy) and *Æschynomene aspera* Willd. ave been studied.[5] The former has no annual rings and consists chiefly f prismatic cells (Fig. 163) with broad lumen and thin walls which in oss-section are hexagonal, arranged in radial rows (*A*), in radial section, uadrilateral in tiers (*C*), and in tangential section, six-sided with wedge-aped ends (*D*). The following description is by Solereder: " The nd surfaces have a sieve-like structure, owing to the presence of numerous ores (Fig. 163, *B*); few if any pits occur on the longitudinal walls. hese cells, as examined by me, contain only air; Moeller, however, in one or two layers; their cells are radially elongated, the walls between adjoining cells in the same row containing an extraordinarily large number of pits. In addition to narrow medullary rays, the old wood of *Herminiera Elaphroxylon* also contains broader rays, within each of which is a strand of spiral vessels surrounded by pitted vessels with broader lumen. These rays extend a greater or lesser distance toward the pith. KEBAHN has shown that the vessels in the broad medullary rays correspond to the xylem of a root formation, which in *Herminiera* is placed between a broad medullary ray and a lenticel on the surface of the stem corresponding to the ray." *Erythrina Crista galli* L. also has a similar formation, but, according to J. MOELLER, the vessels are in the prism cells and not in the wood fiber bands.

---

[1] Wiesner: Rohstoffe. 1. Aufl. 578.

[2] Moeller: Bot. Ztg. 1879, 719.

[3] Moeller: Realenzyklopädie d. ges. Pharm. 2. Aufl., **12**, 350.

[4] Moeller: Pharm. Centralhalle, 1886, 240–242.

[5] Solereder: Systematische Anatomie der Dicotyledonen. Stuttgart, 1898, 312.

II. MONOCOTYLEDONOUS STEMS.

RATTAN.

Rattan is the straight, slender, cylindrical, very tough, climbing stems of different species of *Calamus* (order *Palmæ*). The stems vary from the size of a finger to an inch in diameter. The plant is a native of Malaysia, and the world's supply comes chiefly from the Sunda Islands and the Molukkas by way of Holland, and from the Philippines, Malacca, and Indo-China by way of Singapore. Rattan is also exported from the west coast of Africa in the region of the Niger, and from Cameroon. The best quality is obtained from the rattan palms grown in the land of the Battas in Sumatra and Banjarmassin in Borneo. Among the species yielding rattan are *Calamus Rotang* L., *C. rudentum* Lont., *C. Royleanus* Griff., *C. micranthus* Bl., *C. viminalis* W., and the African species *C. niger* W. "Genuine rattan sticks" are obtained from *C. Scipionum* from Cochin-China, where this palm is known as "Heotau".

Rattan canes are tawny yellow or brownish on the surface, delicately striate or smooth, strongly lustrous, and so hard, owing to the deposit of silica in the epidermis, that a knife grates when used in scraping or cutting the rind. On removing the lustrous outer layer, it will be noted that the inner layers are gray or reddish white, dull, and, in consequence of their fibrous structure, are very easily split into thin strips of great tensile strength and elasticity. These properties give rattan its value for use in braided articles. The strips from the outside, with the smooth outer surface, are employed for caning chairs, settees, wagon bodies, etc., while lusterless strips from the inside of the cane serve for making furniture, baby carriages, baskets, sieves, mats, rope, covering for demijohns, and various other useful articles. "Genuine rattan canes" consist of only one joint (internode) and must not have knots (leaf scars). Short-jointed black-ringed rattan sticks, which are especially pliable and elastic, are also used for walking-sticks under the name of sugar cane. Brown strips several centimeters long serve as a substitute for piassava fiber. Slender sticks impregnated with caoutchouc are used instead of whalebone in the frames of large umbrellas.

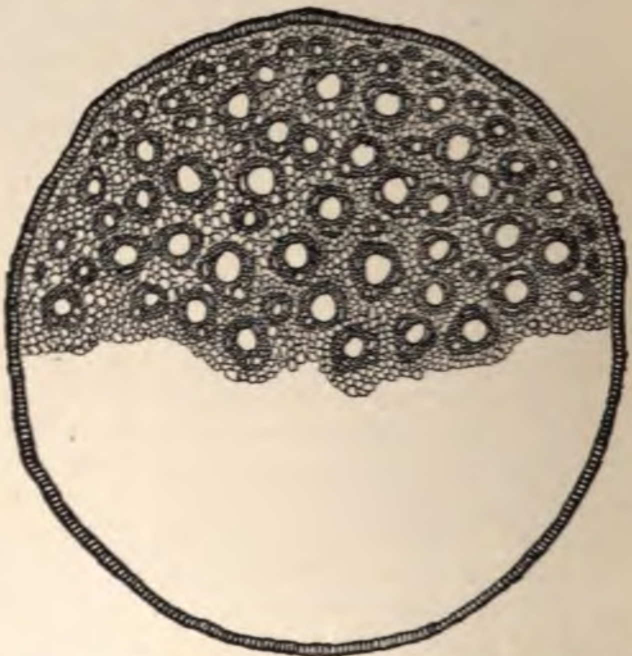


FIG. 164. Rattan (*Calamus Rotang*). Cross-section of Stem. ×60. (BECKER, from Reess' Botanik.)

Shows outer epidermis and numerous scattered bundles within. The outer bundles consist of bast fibers without vessels.

From the above statements it is clear that the technical microscopist may be called upon to decide whether a braided or woven article is made from rattan, or whether some other material has been substituted. If the pieces are large, an examination of the external characters may be sufficient to identify the material, otherwise sections are examined with the lens and under the microscope.

Even with the naked eye it is evident in cross-section that rattan parts: [illegible] ...n as **FIBRO-VASCULAR BUNDLES** or s to be [illegible] ...sist always of two sharply defined parts, uniform [illegible] ...he xylem, wood, or hadrom.[1] also ne[illegible] ...by the so-called **Sieve Tubes** (Fig. 167), eably [illegible] ...y the fusion of cells arranged end to end eye. [illegible] ...n (see "companion cells" below)—and ided wi[illegible] ...ith numerous holes ...Plates. These sieve ...ls of the phloem. In ...phloem contains paren- ...nchyma) and in very ...anied by a bast-fiber ...loem was known as the ...is designation has been ...is not the bast cells, but ...e the characteristic ele- (WIESNER). From the ...the position and signifi- ...nical bast fibers such as

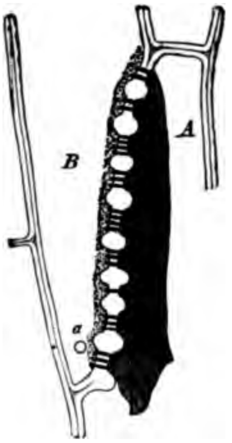


FIG. 167. Sieve Plate from the Bark of *Vitis vinifera*. (DE BARY.)

Tangential section through the scalariform boundary wall of two members, *A* and *B*, of a sieve tube. The thick mucilaginous mass of *A*, shrunken by alcohol, penetrates all the sieve pores into *B*. *a* starch grain.

...as its characteristic tissue ...f their substitute form, the ...libriform cells are present, ...ponents. The fibro-vascular ...p of thin-walled cells capable ...known as the **Procambium**. ...ly into a permanent tissue ...the bundle so formed is not ...owth and is known as a **Closed Bundle**. The ...dons, and therefore of rattan, are of this class. ...meristematic cells, that is cells capable of further ...m a cambium layer between the xylem and phloem ...cells during succeeding epochs of growth can con- ...phloem on one side and xylem on the other, the ...ns, being in the form of annual rings (see p. 203). ...nd are known as **Open Bundles**; in them can be ...phloem and xylem, but also the cambium layer.

---

[1] ...ce the name hadromal, see p. 102.

We now understand what is meant when it is said that rattan has closed bundles. The bundles have in the xylem a large central vessel with reticulated thickened walls (Figs. 165 and 166) and several small spiral vessels. On both sides of the central vessel are large sieve tubes and sparingly developed phloem parenchyma, while a thick group of sclerenchyma elements or bast fibers, in cross-section bowed or sickle-shaped, extends about the edge of the vascular bundle, forming a protecting sheath and also contributing to the strength and toughness of the stem. The bundles, consisting entirely of bast fibers already described, also serve as mechanical elements.

The elongated cells accompanying the sieve tubes, known as **Companion Cells,**[1] contain protoplasm, but never starch, and have pores on the wall adjoining the sieve tubes. Both sieve tubes and companion cells are derived from the same kind of cells. The mother cells divide into daughter cells by the formation of longitudinal partitions, the larger of these developing into sieve tubes, the smaller into companion cells. It remains to be mentioned that in many closed vascular bundles a part of the original cambium takes on the form of a permanent tissue; the cells undergo no considerable change in form, remain free from pits and thickenings, and contain protoplasmic contents. These cells are called **Cambiform Cells.**

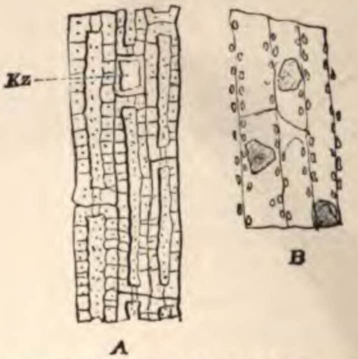


FIG. 168. Epidermis of the Stem of Rattan in Surface View. ×300. (T. F. HANAUSEK.) *A* in potash: *Kz* short cell.—*B* silica skeleton obtained by burning to an ash.

The Ground Tissue in which the vascular and fiber bundles are imbedded consists of parenchyma.

If it is desired to determine positively that a certain small object consists of rattan, an examination of the **Epidermis**, if present, is desirable, as this has a very characteristic appearance. The microscopic characters of this tissue are here only briefly described. In the chapter on leaves we learn further details as to the structure of epidermal cells.

---

[1] WILHELM: Beiträge zur Kenntniss des Siebröhrenapparates. Leipzig, 1880.

The epidermis of rattan consists of longitudinally elongated rectangular, strongly thickened and silicified cells (Fig. 168, *A*), between which are a considerable number of short cells and also occasional stomata. If a piece of this tissue is burned to an ash, a colorless silica skeleton (*B*) is obtained in which the cell outline, with a row of pores on each side, is clearly evident. The situation of the short cells is also easily observed. The epidermal cells are of somewhat uniform breadth (14.4–18μ) but of very variable length, the short cells ranging up to 36μ, the long cells up to 180μ and over.

OTHER STEMS OF MONOCOTYLEDONS.

Other monocotyledonous stems of technical importance are those of numerous palms, of bamboo (see analytical key, p. 243), and of sugar cane.[1] The cuticle covering the epidermis of sugar cane is itself covered by a coat of wax[2] in the form of fine rods 100–150μ long (Fig. 169). These rods are straight on the lower end but hooked on the free end. Similar incrustations of wax, in the form of granules, make up the bloom of many leaves and fruits (e.g., plum) and, when in thick crusts, various vegetable waxes of technical importance[3] (e.g., carnauba wax).

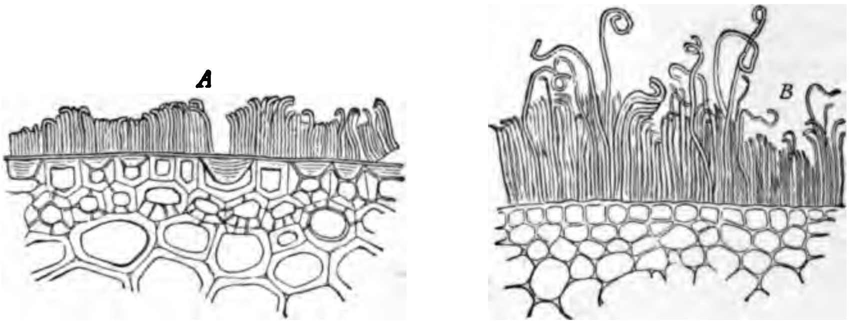


FIG. 169. Cross-section through the Periphery of the Stem of Sugar-cane (*Saccharum officinarum*), showing Coating of Wax in Rods. (DE BARY.)
A through internode; *B* through node.

---

[1] WIELER: Anatomie des Stockes von Saccharum. Beiträge zur wissensch. Botanik. 1897, Bd. 2.

[2] DE BARY: Anatomie der Vegetationsorgane, 88.

[3] WIESNER: Rohstoffe. 2. Aufl. 1900, 522.

III. SUBTERRANEAN ORGANS.

Monocotyledonous Roots and Rhizomes.

Under this head are included rootstocks or rhizomes, tubers, bulbs, and true roots. Rhizomes and tubers are underground stems, bulbs consist of a short axis surrounded by fleshy leaves, while tuberous roots are enlargements of the roots resembling true tubers. The marked characters which distinguish the aerial stems of monocotyledons and dicotyledons are also noticeable in the subterranean organs.

We will now consider the histological structure of some examples of these organs,[1] although their technical importance compared with that of woods is insignificant.

TURMERIC.

Turmeric, or curcuma, is much employed in the arts, chiefly for coloring wood, paper, leather, and metal lacquers. It is also extensively used in the East and to some extent in England and America as a spice. It consists of the dried rhizome of *Curcuma longa* L. (order *Zingiberaceæ*), which is indigenous to India and southern China, and is cultivated in Java and Réunion. Chinese turmeric is the best grade.

Commercial turmeric consists in large part of elongated cylindrical sticks, known as long turmeric (*Curcuma longa*), mixed with a few egg- or pear-shaped tuber-like bodies, known as round turmeric (*Curcuma rotunda*).[2] The sticks of long turmeric are straight or knee-shaped, sometimes with short branches, longitudinally wrinkled and faintly ringed, on the outside gray-yellow or pale yellow, on the fractured surface smooth, waxy, dark orange or gamboge-yellow, sometimes even greenish black. Owing to its high specific gravity it sinks in water; owing to its hardness it cuts like horn. Its relation to ginger is indicated by its odor. It has a spicy taste and on chewing colors the saliva yellow.

Round turmeric, which occurs rarely in the drug, consists of rounded bodies 2–3 cm. long, up to 2 cm. broad, marked with numerous ring-shaped scars of the lower leaves.

According to TSCHIRCH,[3] these round bodies are, as it were, secondary central tubers and, like the primary tubers which decay after the dying down of the vegetative organs, bear side branches or long turmeric. Round turmeric may then be considered as leaf-bud internodes.

---

[1] A. MEYER: Wissenschaftliche Drogenkunde. Berlin, 1891, 1. Theil, 177.

[2] T. F. HANAUSEK: Nahrungs- und Genussmittel. Cassel, 1884, 239. VOGL: Arzneikörper (Commentar, etc.), 1892, 328. *Idem:* Wiesner's Rohstoffe. 2. Aufl. 1903, **2**, 509.

[3] TSCHIRCH u. OESTERLE: Anatomischer Atlas. Table 24. p. 99.

If we examine the cross-section of long turmeric with a lens, we will observe numerous light-yellow dots and a light-yellow round line in a dark-yellow ground mass. These features, as well as the external appearance, are sufficiently characteristic for the identification of the whole material. Since, however, turmeric is often sold ground and only in this condition can be used for the extraction of the coloring matter, it is necessary to understand its microscopic structure.[1]

The rhizome,[2] in its original condition, has an epidermis with numerous hairs, beneath which is a **Periderm**, or cork layer. Only the periderm forming the covering of the rhizome is usually found on the commercial product. This tissue, which we will consider more in detail in the chapter on barks, consists of thin-walled, empty, tangentially elongated or flattened cells arranged in radial rows. In addition to this highly characteristic arrangement, the fact that the walls of the cork cells are suberized, i.e., have lamellæ of **Suberin**, and do not therefore give the cellulose reaction directly, is of further diagnostic importance. Cork tissue is nearly impervious to both air and water.

The form of the cork cells in surface view is rather sharply polygonal, in cross-section rectangular; the cells are very short 5–6-sided prisms with their principal axis (in the geometric sense) perpendicular to the longitudinal axis of the rhizome, or, in other words, parallel to the radius.

To bring out clearly the histological elements of the bark and central tissues, it is recommended to place in water sections previously warmed in alcohol, wash with cold water, add a trace of potash, wash again, and finally mount in glycerine. By this treatment the balls of starch paste are largely removed, the vascular bundles are rendered beautifully distinct, and the resin cells, owing to the color imparted by the potash, are clearly evident.

Investigation, in longitudinal and cross section, of the tissue underlying the periderm shows us that this consists largely of thin-walled parenchyma cells which are rather large and only slightly elongated in an axial direction. Further inward we find vascular bundles and finally, bounding the parenchyma, a narrow layer of tangentially elongated suberized thin-walled cells without contents. This latter layer, which we observed under the lens as a light-yellow line, is designated the **Endodermis**, since it separates the rind, consisting of the outer cork layer and the underlying parenchyma or cortex, from the central part of the rhizome. In many places this endodermis is interrupted by vascular bundles which extend from the cortex into the central cylinder.

---

[1] ARTHUR MEYER: Beiträge zur Kenntniss pharmaceutisch wichtiger Gewächse, II. Ueber die Rhizome der officinellen Zingiberaceen, *Curcuma longa*, etc. Arch. Pharm. 1881, **218**, 401–429. TSCHIRCH u. OESTERLE: *loc. cit.* 100–102.

[2] TSCHIRCH u. OESTERLE: *loc. cit.* 100.

We will now study the vascular bundles occurring in the rind near the endodermis. In cross-section we note the striking appearance of the vessels which are arranged in 1–2 rows or more or less irregularly.

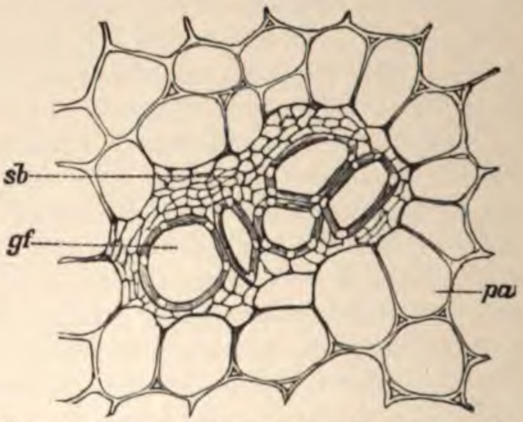


FIG. 170. Collateral Vascular Bundle of Turmeric (*Curcuma*) in Cross-section. (T. F. HANAUSEK.)
sb phloem; *gf* xylem with five large vessels; *pa* ground tissue of parenchyma.

Opposite the xylem or vascular part of the bundle lies the phloem, consisting of parenchyma cells and sieve tubes. Such a bundle is called **Collateral**, in contradistinction to the **Concentric** bundle in which the xylem is encircled by phloem (or else a central phloem is encircled by xylem), or to the **Radial** bundle, the xylem and phloem of which are in alternating rays. If, in a collateral bundle, a phloem is developed on the inner as well as the outer side of the xylem, the bundle is called **Bicollateral.** We find in turmeric mostly collateral bundles (Fig. 170), but in the central cylinder bicollateral and concentric bundles are also present.

Now that we have gained an idea of the cell structure of the rind, it remains to study the cell contents. According to the contents, we may listinguish two kinds of cells, namely, **Starch Cells** and **Secretion Cells.** The cells of the rind (and also those of the central cylinder) are for the nost part filled with starch, which in the fresh rhizome lies in a colorless ell sap.

In the commercial product, however, individual starch grains are eldom present, but the starch is in the form of gelatinized masses, since in reparing the rhizomes for the market they are kept from twelve hours to day in boiling water so as to destroy their vitality and obviate the danger f sprouting. The gelatinized masses have delicate reticulations on the urface corresponding to the swollen starch grains, and are colored yellow wing to the presence of **Curcumin**, one of the substances contained in he secretion cells, which, owing to the action of the hot water, becomes listributed through the tissues. Powdered turmeric often contains well-reserved starch grains. These probably were originally contained in he tuberous bodies sometimes developed from the roots on the primary ootstock. Since these bodies, rich in reserve starch, do not have the ower of sprouting, it is probably deemed unnecessary to scald them. These unchanged grains should not be mistaken for the starch grains of dulterants. They are elliptical, oval, or hatchet-shaped, flattened, 0–60μ (according to TSCHIRCH 10–45μ) long.[1] Usually they have a apering point at one end, in which is the hilum. Being flattened, they ppear rod-shaped when viewed on edge. In addition to starch grains, ery small crystals of calcium oxalate are also present. TSCHIRCH[2] nds that on treating a section with sulphuric acid numerous needles f calcium sulphate are formed, from which it may be concluded that, in ddition to the small amount of calcium oxalate, other lime salts are resent.

Distributed among the starch parenchyma cells are a few large secreion cells with suberized walls, i.e., with an outer lamella of cork. The ecretion consists of a colorless essential oil and the coloring substance urcumin. As already noted the secretion, on soaking in hot water, is listributed through the tissues and many of the secretion cells are empty.

The coloring matter, which has long been used for making test-paper, hows the following relations:[3]

---

[1] T. F. HANAUSEK: Nahrungs- und Genussmittel, 240.

[2] TSCHIRCH u. OESTERLE: *loc. cit.* 100.

[3] TSCHIRCH u. OESTERLE: *loc. cit.* 93 (under Crocus). The reactions may be carried ut in drops of the reagents on a slide placed on a piece of white paper. The powder is laced in the drops and stirred with a rod.

Concentrated Sulphuric Acid: deep orange-yellow, changing from the edges inward to orange-red; finally a red-brown precipitate; acid colorless.

Dilute Sulphuric Acid (1 drop to 2 drops of water): carmine-red in places (chiefly in the secretion cells), elsewhere colorless; acid colorless.

Concentrated Hydrochloric Acid: brownish yellow; acid colorless.

Potash: deep orange, becoming still deeper on standing; color permanent; alkali uncolored.

Ammonia: deep orange, less permanent than with potash.

Water: no change; water colorless.

Boric Acid: If thin sections are dried several times with a solution of boric acid in dilute hydrochloric acid (1 gram boric acid, 1 cc. hydrochloric, 100 cc. water), the yellow color becomes carmine-red, changing, on cautious addition of a slight excess of dilute ammonia, to violet. Sections colored orange by potash are changed again to yellow by acids.

It remains to describe the structure of the central cylinder. The ground tissue is not different from the parenchyma of the rind; it consists of starch cells and secretion cells. The central cylinder, however, is rich in vascular bundles in which are usually 2–7, less often up to 15, vessels. These vessels have either spiral or reticulated thickenings. Mechanical elements, such as libriform cells or other sclerenchyma elements, are absent entirely.

The arrangement of the vascular bundles is described by A. Meyer and Tschirch and Oesterle.[1] Ginger, the rhizome of *Zingiber officinale* Roscoe, a plant of the same family, is very similar to turmeric in structure.

ORRIS ROOT.[2]

Although orris root, the rhizome of several species of *Iris* (*I. Germanica* L., *I. pallida* Lam., *I. Florentina* L.), being from a monocotyledonous plant, has the same general structure as turmeric, it shows some very remarkable peculiarities as regards cell contents that deserve special notice.

As found on the market, orris root is dried and decorticated. It consists of a flattened, at first clustered, later, after the dying of the end sprouts, cymose and forking rhizome with constrictions corresponding to each year's growth. On the upper side are the scars of the lower leaves, on the lower side the small circular root scars. The product is white or yellowish white, hard, heavy, and has an even fracture and the well-known odor of violets.[1]

---

[1] *Loc. cit.*

[2] Hartwich: Realenzyklopädie d. ges. Pharm. 2. Aufl. 1906, **7**, 139. Tschirch u. Oesterle: *loc. cit.* Table 29, p. 121. Vogl: Arzneikörper, 322. *Idem:* Wiesner's Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903, **2**, 504.

On the elliptical or circular cross-section there may be seen under a lens a thin white rind, a very delicate endodermis, and a yellow-white central cylinder with numerous vascular bundles situated mostly in the outer part. Bundles also occur sparingly in the cortex.

The undecorticated rhizome is covered with a periderm up to 25 cells thick which is not found on the commercial product. As in the case of turmeric, the ground tissue of the rind and central cylinder is parenchyma, but the cells are relatively thick-walled, richly pitted, with intercellular spaces of various sizes. Under the cork cells of the periderm is a tissue of a collenchymatous nature consisting of cells with thickened angles, which serve a mechanical purpose. The vascular bundles of the rind are collateral; those of the central cylinder, however, are concentric, since the xylem encircles the central phloem more or less completely. The vessels are spiral and scalariform and are 20–35μ broad; the sieve tubes are very distinct; mechanical elements are lacking in the bundles.

The cell contents are studied in water mounts. The ground tissue of parenchyma is rich in starch; the starch grains (Fig. 171, *A*) are simple, seldom in aggregates, elongated, conical, flattened or hollowed on the small end, rounded on the large end. The larger grains are 25–50μ long and 10–20μ broad, with one, two, or more hilum slits. The flattened or hollowed end marks the place where the leucoplast or starch-forming body was attached (see p. 31). TSCHIRCH states that in no other plant is this place so distinct as in these mature starch grains. In addition to starch, the cells also contain fatty oil in protoplasm, a soft resin, traces of essential oil, etc. If light is thrown on a section, the reflection from numerous crystals may be seen with the naked eye. Orris root is characterized by the presence of calcium-oxalate crystals remarkable alike for their enormous size (200–280μ long, 25–30μ broad) and beautiful form. These crystals are prismatic, in cross-section quadrangular or rectangular, with a reentrant angle at one end and a sharp point at the other (Fig. 171, *B*). They are contained in very thin-walled long tube-like sacs (*B*, *m*), the morphological significance of which is learned by a study of the development. We have already learned that intercellular spaces occur in the ground tissue (Fig. 171, *C*). TSCHIRCH u. OESTERLE (Anatomischer Atlas, p. 122) describe the sacs as formed in these intercellular spaces from the adjoining cell walls. The same authors, however, in more recent investigations (*loc. cit.* Zusätze und Berichtigungen, *Rhiz. Iridis*) have found them to be true cells which have grown only in length and have become separated from the adjoining cells, thus forming what appear to be pockets projecting into the intercellular spaces.

---

[1] The fresh rhizome does not have a violet odor; this is developed on drying. Because of the odor the product is used in the preparation of perfumes, tooth powders, sachet powders, cordials, for mixing with snuff, etc. Orris root contains a peculiar glucoside, *Iridin*, discovered by TIEMANN and LAIRE. (Ber. Deutsch. Chem. Gesell. 1893, **26**, 2011.)

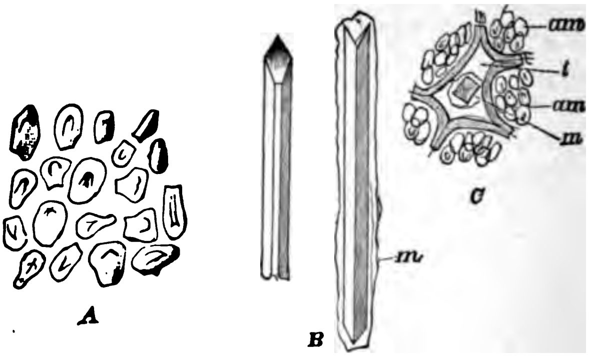


FIG. 171. Cell Contents of Orris Root (*Iris*). (T. F. HANAUSEK.)

A starch grains, mostly of typical forms. × 250.—*B* calcium oxalate crystals: at the left part of crystal prism; at the right twin crystal in *m* membranous sheath.—*C* cross-section from the parenchyma, showing *i* intercellular space, (in water): *am* starch grains in adjoining parenchyma cells (only a small part of the walls shown); *m* membranous sheath inclosing crystal.

With the aid of the starch grains and these crystals it is not difficult to determine whether a given powder is ground orris root and to pronounce on the purity of the commercial product.

Dicotyledonous Roots and Rhizomes.

Among the dicotyledonous roots and rootstocks of technical importance are alkanna root, soapwort, sassafras root (*Laurus Sassafras* Bauh.), longwort (*Archangelica officinalis* Hoffm.), madder, the root of *Rumex hymenosepalum*, known in Arizona as Canaigre,[1] and in Texas as tanner's ock, etc. Chicory root is extensively used as a substitute for coffee; ince it contains a histological element not found in the products escribed on the foregoing pages, namely, the latex tubes, we will conder its structure in detail further on. Of the other underground prodcts named, madder root is not nearly of so great importance or so idely distributed as formerly, since its coloring principle is now preared synthetically.

---

[1] Contains 23% of tannin.

ALKANNA ROOT.

Alkanna root (*Alkanna tinctoria* Tausch, order *Boraginaceæ*) is used hiefly for coloring salves, pomades, hair oils, and, in microscopy, for oloring resinous and fatty substances. According to A. Vogl,[1] the root f *Onosma echioides* L. (*Radix Anchusæ luteæ*), a substitute for alkanna oot, is more commonly found on the European market than the genuine roduct. This substitute is also shipped from Provence under the name f "Orsanette".

True alkanna root has a thin, brittle, scaly, black-violet outer rind oosely surrounding the inner rind and the wood. The outer rind contains he coloring principle **Alkannin** (or alkanna red), which dissolves in lcohol, ether, fatty and essential oils to a red, and in alkalies to a blueiolet, solution. The inner rind consists of radially arranged, thin-walled arenchyma cells and phloem elements. Vogl states as follows: "The utermost zone of the inner rind, consisting of but a few cell layers and isible under a lens because of its beautiful red color, contains drops f coloring matter which, on handling, color the fingers a fine red. The ood bundle consists in large part of thin-walled parenchyma in which re both broad and narrow rows of reticulated pitted vessels."

SOAPWORT ROOT.

Soapwort root is widely used for cleaning wool, fabrics, etc.[2] Common oapwort root, known in pharmacy as *Radix Saponariæ rubræ*, is from *aponaria officinalis* L.; white or Levantine soapwort formerly was btained from *Gypsophila Struthium* L., grown in Spain; at present, however, according to the investigations of Flückiger,[1] it is obtained from *G. Arrostii* Gussone (southern Italy) and *G. paniculata* L. (Asia Minor).[2]

---

[1] Arzneikörper, 377.

[2] The bulbs of the California soapwort (*Chlorogallum pomeridianum* Kunth, order *iliaceæ*) are also used in cleaning. When dry they contain 6.95% of saponin. See Amer. our. Pharm. 1890, 600 (Pharm. Post. 1891, 254).

COMMON SOAPWORT as found on the market consists partly of the tap root of one- and two-year-old plants, which is the best product, and partly of the side roots springing from the rhizome of old plants and of the runners. Like most roots, the true roots of soapwort are without pith, but the runners, which are really underground stems, have a distinct pith or a pith cavity and in addition are characterized outwardly by the opposite knots. The roots[3] are only 4–8 mm. thick, red-brown, and in cross-section show a light lemon-yellow, woody structure without pith or medullary rays. The outer bark consists of periderm, the middle bark of parenchyma, while the inner bark contains parenchyma and phloem. Thin-walled wood fibers and rather large spiral vessels occur in the wood. Formless and colorless lumps, consisting in large part of **Saponin**,[4] are found in the parenchyma. According to Alexander Rossoll,[5] saponin can be detected microchemically by concentrated sulphuric acid, which colors the saponin bodies contained in the cells first yellow, then red, and finally blue-violet and also dissolves them. The author's experiments[6] have shown that Lafon's methods may also be used. Lafon uses for the identification of digitalin a mixture of one part of alcohol and one part of concentrated sulphuric acid, and warms until a yellow color appears. If a drop of dilute ferric-chloride solution is then added, a blue color is obtained which remains unchanged for a long time. Pure **Sapotoxin**, as has been shown by Kobert, gives exactly the same reaction. The rind of soapwort, after warming with the alcohol-sulphuric acid mixture, exhibits first a rose-red and finally a violet color, while the wood is yellow-green and shows isolated red streaks. After addition of dilute ferric-chloride solution, the rind is gradually decolorized and a faintly red precipitate forms in the fluid.

---

[1] Arch. Pharm. **226**, 1890.

[2] *G. paniculata*, together with other species of *Gypsophila*, is extensively cultivated in parts of Austria for dry bouquets (e.g., near Kirchberg in lower Austria).

[3] For detailed description of microscopic structure see Vogl: Ztschr. allg. Österr. Apoth. Ver. 1865, 460, and Arzneikörper, 342.

[4] In general this term is applied to vegetable substances of a glucosidal nature which have the power of forming a copious lather with water. According to Kobert, however, there are amorphous and crystalline, poisonous and non-poisonous saponins.

[5] Beiträge zur Histochemie der Pflanzen. Sitzb. Wien. Akad. 1884, **89**, I, 143.

[6] Zur Kenntniss des Vorkommens und Nachweises der Saponinsubstanzen im Pflanzenkörper. Chem. Ztg. 1892, **16**, Nos. 71 and 72.

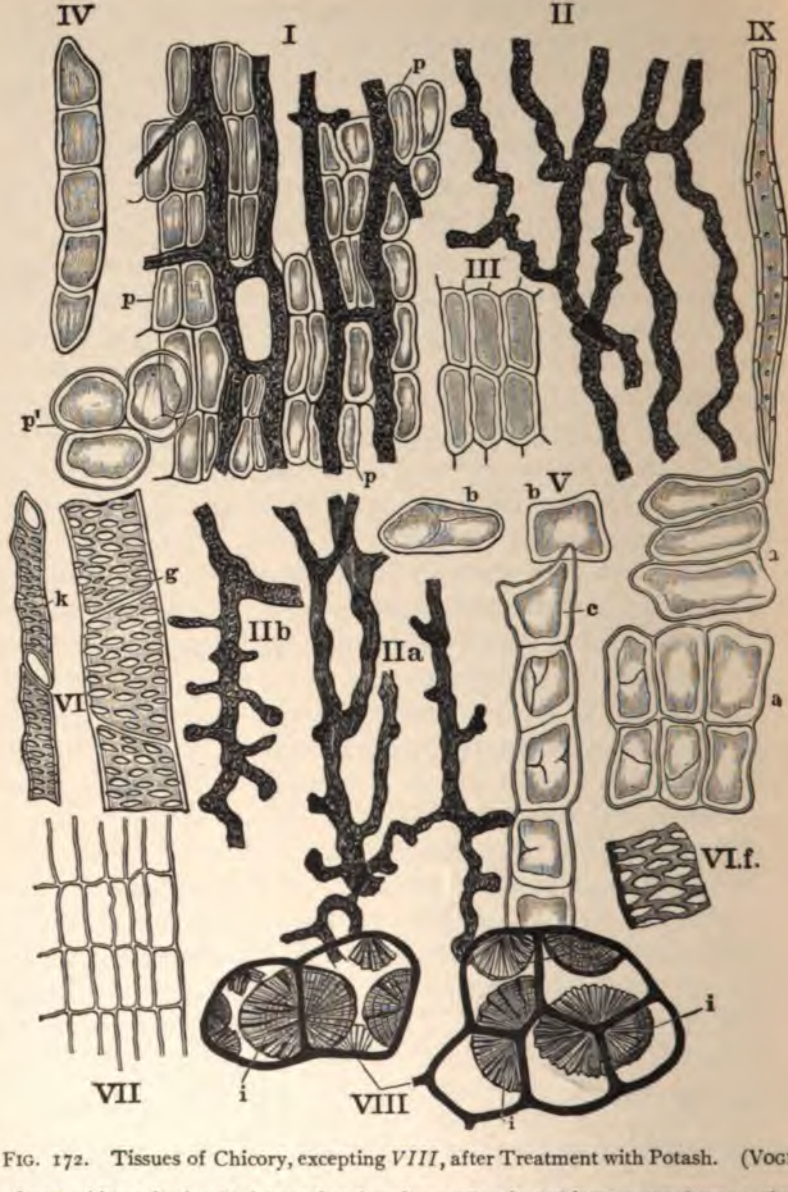


FIG. 172. Tissues of Chicory, excepting *VIII*, after Treatment with Potash. (VOGL.)

I part of inner bark with latex tubes forming meshes in *p* phloem parenchyma; *p'* parenchyma cells of middle bark.—*II* latex tubes; *IIa*, *IIb* latex tubes with many blind ends.—*III* phloem parenchyma.—*IV* and *V* parenchyma cells of middle bark and medullary rays (*a*, *b*), partly in spindle-shaped aggregates (*c*).—*VI* narrow (*k*) and broad (*g*) reticulated vessels; *VI*, *f* fragment of vessel.—*VII* cork in cross-section.—*VIII* parenchyma from the dried root, strongly magnified, showing *i* inulin sphæro-crystals.—*IX* sclerenchyma fiber from xylem, found rarely in chicory.

(VI). The principal part of the wood cylinder consists of parenchyma with rounded, rounded-polyhedral, or barrel-shaped cells. All the parenchyma cells contain **Inulin** (see p. 50 and Fig. 172, VIII). According to A. VOGL,[1] iodine green colors the membrane of the parenchyma cells blue and the walls of the vessels green; chlorzinc iodine colors all the membranes blue and the walls of the vessels greenish yellow. The callus and sieve plates of the sieve tubes usually contain distinct pore canals and are colored a beautiful blue on successive treatment with potash and hæmatoxylin-saffranin. Small, simple starch grains occur in the sieve tubes.

Latex Tubes[2] are not only excretory but also, according to HABERLANDT, conducting organs. They are, for the most part, continuous, much-branched tubes, always with non-lignified and non-suberized cellulose walls, and form a continuous system in the part in which they occur. TSCHIRCH,[3] in referring to the location of the latex tubes in the primary tissues, states that in the case of roots they are in the phloem of the bundle, in the case of stems, petioles, and leaf ribs, in the phloem parenchyma near the sieve tubes, following the longitudinal course of the bundle; if a bast sheath is present they are always outside of this.

Two classes of latex tubes, depending on the manner of development, are recognized: (1) jointless and (2) jointed.

Jointless Latex Tubes occur chiefly in the *Euphorbiaceæ*, *Urticaceæ*, *Artocarpeæ* (in the fig), *Apocynaceæ*, and *Asclepiadaceæ*. They are developed from one meristematic cell which grows to an enormous length and, at the same time, forms branches, so that it finally resembles a much-branched tube, which, however, is not connected with other latex tubes of the organ. Particularly fine examples of jointless latex tubes occur in the fig and the coffee substitute prepared from it.

Jointed Latex Tubes (Fig. 172, I and II) are formed in a very different manner. These are developed similarly to vessels of the xylem from rows of elongated cambium cells, the cross-walls of which are absorbed, thus forming uniform tubes. In this manner are developed the latex tubes of chicory, as well as those of all composite plants of the suborder *Cichoriaceæ*,[4] also in species of the *Campanulaceæ* and most species of *Papa-*

---

[1] Die wichtigsten vegetab. Nahrungs- und Genussmittel, 335.

[2] TSCHIRCH: Angewandte Pflanzenanatomie, 518. Numerous references to other articles are given by this author.

[3] *Loc. cit.* 520.

[4] VOGL: Ueber die Intercellularsubstanz und die Milchsaftgefässe in der Wurzel des gemeinen Löwenzahnes. Sitzb. Wien. Akad 1863.

veraceæ. The latex tubes of chicory root are arranged in radiating groups, thus giving the rind a radially striated appearance in cross-section. **Latex** is a true emulsion, consisting of exceedingly great numbers of minute granules suspended in a colorless fluid. It is known to consist chiefly of proteid matter, gum, tannin, pectin, and lactucon.

Latex tubes are rendered particularly distinct by laying sections in iodine tincture of a light-yellow color. They absorb iodine, which color them yellow. Chicory is often adulterated, especially with roasted suga beets. This material contains no latex tubes, but is easily identified b the crystal sand cells, which do not occur in chicory.[1]

IV. BARKS.

The barks of dicotyledonous and coniferous woody plants, which a characterized by a high tannin content or the presence of coloring materia alkaloids, etc., are among the most valuable of industrial raw material Since, as in roots, the valuable constituents are chiefly in the form cell contents, a knowledge of the microscopic characters and especiall the microchemical reactions of the cell contents is of great practica importance. Preparatory to examination, most dried and shrivelle barks need to be softened and swelled by potash or by soaking for a long time in chloral hydrate. A complete knowledge of the structure of barks can be gained only by studying transverse, radial, and tangential sections, although for practical purposes the first of these is often sufficient. Since the investigation of old barks presents numerous difficulties, the beginner is recommended to confine his attention at first to thin young barks, thus mastering the general principles of bark structure.

In the foregoing section we have learned that commercial barks consist of three parts, of which only the two outer, the periderm and the primary bark (cortex), are true bark, the so-called inner bark being the phloem portion of the bundle ring.

The general details of histological structure will be learned from the following descriptions of representative barks.

CORK.[2]

As has already been noted, cork or periderm, in the scientific sense of the term, is a tissue formed in all dicotyledonous and gymnospermous woody plants beneath the epidermis, and is characterized by the regular arrangement of the cells in radial rows also, owing to the deposition of suberin, by the resistance of the cell walls to reagents. Commercial cork consists almost exclusively of the outer bark of the evergreen cork oak (*Quercus suber* L.[1]) and the deciduous Spanish oak (*Q. occidentalis* Gray). In addition to these species, which are distributed over the western Mediterranean region (especially Algiers), *Q. Ilex* L., growing about the Adriatic, and the South Tyrolian species *Q. Pseudosuber* Santi yield cork of very inferior value.[2] The cork first formed on the young trunk, known as " male " cork, being of little commercial value, is carefully removed, after which a new inner cork-producing layer (phellogen or cork cambium) appears, which by energetic cell division forms good or " female " cork. After ten years' growth the cork layer is 17–26 mm. thick. This is removed in plates, taking care not to disturb the phellogen, and the plates are piled one on the other, weighted with stones, dried, and trimmed with sharp knives. "Black cork" is prepared by charring with a flame. The best grades come from Andalusia and Catalonia, although the product from Algeria and southern France is of nearly equal value.[3]

---

[1] See also PAUL JAKOB: Naturaliste, 1897, 131, 153. Jahresbuch der Naturwissenschaft von Wildermann, 1898, **13**, 192.

[2] v. HÖHNEL: Wiesner's Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1900, **1**, 725.

Cork is chiefly used for stoppers, in thin sheets for shoe soles, for cork jackets, for linings of hats, for bottoms of insect cases, for covering handles, for the preparation of linoleum, for life preservers, for floats on seines, for the preparation of burnt cork (Spanish black), etc. No substitute can fully take the place of cork, although, where it is merely a case of diminishing the specific gravity, cork woods (p. 253) may sometimes be substituted. The cork-like bark of the black poplar (*Populus nigra* L.) is used to some extent as a substitute for true cork.[4]

MICROSCOPIC STRUCTURE.

Transverse and radial-longitudinal sections show, even to the naked eye, parallel, tangentially arranged, wavy lines which in a sense are analogous to annual rings, since the cork layers between these rings represent the growth of a single year.

We also find radially arranged, constricted, cylindrical rows of cells of a darker color and radically different appearance from the other tissues. These are imbedded in the ground tissue similar to medullary rays, but in other respects are not similar. They are known as **Lenticels.**[1] The groups of cells fall away from the dry pieces of cork, especially on the cut surface, thus forming cavities. The function of lenticels is to furnish communication between the inner tissues and the air, thus forming a kind of ventilation system. According to DE BARY,[2] a lenticel may be described " as a local, biconvex swelling of the periderm, often extending beyond the surface of the stem as well as inward, which is distinguished from the other tissues by the narrow intercellular spaces between its rounded, suberized, phellodermal, and meristematic cells ". The outer cells of the lenticel, known as **Complementary Cells,** differ from cork cells; they are loosely arranged, form when dry a powdery mass, and in oak cork are kept intact by the tough firm mass of cork tissue which surrounds them and prevents them from disintegrating.

---

[1] E. A. Müller: Über die Korkeiche. K. k. geog. Gesell. Wien, 1900, II, 7. T. Rein: Geog. naturwiss. 1892, I, 137.

[2] According to Merklin (cited in Tschirch's Angewandte Pflanzenanatomie, 284), cork is obtained in Russia from the birch.

[3] Lumey: Le chêne liège; sa culture et son exploitation. Paris, 1893.

[4] Moeller: Anatomie der Baumrinden, 93.

Oak cork is an exception in that the lenticels do not extend beyond the surface (see oak bark, p. 281), but form radially extended chambers. STAHL distinguishes in general between lenticels with loosely arranged complementary cells alternating with thicker intermediate streaks, and those with more closely united cells without intermediate streaks. Especially well-developed lenticels occur on elder bark (*Sambucus nigra* L.). In Fig. 173 are shown the complementary cells (*f*) which have burst through the epidermis and are continually being renewed by a layer of active cells or **Phellogen** (*v*).

It may here be stated that the phellogen forms on the outside cork, and on the inside a permanent tissue, the **Phelloderm** (*p*). We will consider this later in detail. True cork tissue consists of cork cells which, in cross- (Fig. 174) and radial-longitudinal sections, are more or less rectangular, in tangential section irregular and often rounded polygonal, mostly six-sided (Fig. 175); accordingly the cork cells are prismatic, with the base of the prism parallel to the tangential surface, and the axis parallel to the radius. The walls are very thin and wavy; the lumens are large, filled only with air. Small bundles of crystals occur here and there in old cork. This structure explains the well-known physical properties of cork—its low density, its elasticity, as well as its capability, especially when moist, of being compressed to a much smaller volume. The border of the annual zone of growth is characterized by several rows of cells with strikingly thicker walls, the cells themselves being smaller (Fig. 174, *J*). We thus see that the principle underlying the formation of the boundaries of annual rings, namely, the decrease in the size of the cells and lumens and the increase in the thickness of the walls, is exemplified not only in the structure of woods but also of cork. Lenticels contain

---

[1] DE BARY: Anatomie, 575. G. HABERLANDT: Beiträge zur Kenntniss der Lenticellen. Sitzb. Wien. Akad. 1895, **72**. H. KLEBAHN: Ueber die Structur und die Function der Lenticellen, sowie über den Ersatz derselben bei einigen lenticellenfreien Holzgewächsen. (With bibliography.) Ber. Deutsch. Bot. Gesell. 1883, **1**, 113–121. STAHL: Entwicklung und Anatomie der Lenticellen. Bot. Ztg. 1873.

[2] *Loc. cit.* 576.

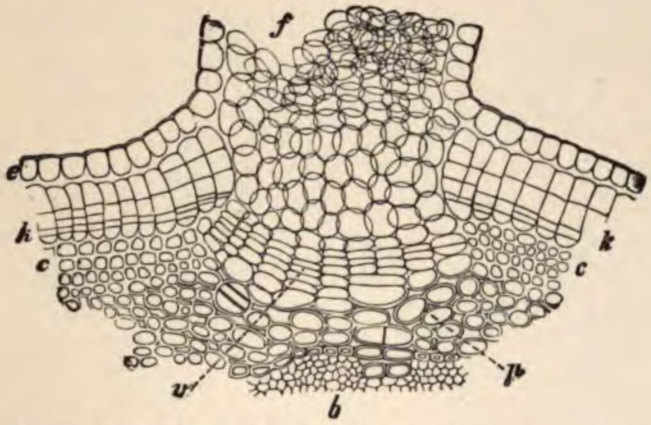


FIG. 173. Fully Developed Lenticel from *Sambucus nigra.* ×100. (STAHL, from Luerssen's Botanik.)

e epidermis, in the middle broken by pressure of the complementary cells *f*; *k* young cork; *v* phellogen, forming cells of the lenticel; *p* phelloderm; *b* bast; *c* collenchyma.

Sclerenchyma Cells, which, like all real stone cells, have thickened, richly pitted, and strongly lignified walls and a lumen filled with deep-brown contents (Fig. 175). Since the union of these cells, not only among themselves but with the cork tissue, is very loose and by thorough drying is almost completely destroyed, it is evident why these sclerenchyma masses become detached. The cork used for the finest stoppers should contain as few lenticels as possible, and these should be very small. For this reason there is a great difference in price between fine cork and coarse, brittle cork with numerous lenticels.

The question suggests itself, why the first-formed, normal "male" cork is useless for most technical purposes. The outer side of the cork rind has broadly wedge-shaped fissures running parallel to the axis of the stem and extending deep into the interior. This part is characterized by its extraordinary hardness. In cross-section we find in the outer part an unbroken row of cell groups, appearing nearly white and consisting of colorless, very strongly thickened sclerenchyma cells. The first cork layers consist of small cells with thicker walls and are of a different (redder) color than those of the following layers. The distinction in color is especially distinct on applying strong potash solution to the cross-section; immediately the first (1–2) cork layers become reddish, the following layers strikingly yellow, but gradually the color becomes more uniform and finally the whole surface is a uniform yellow-brown. From the characters named it is evident why " male " cork is worthless.

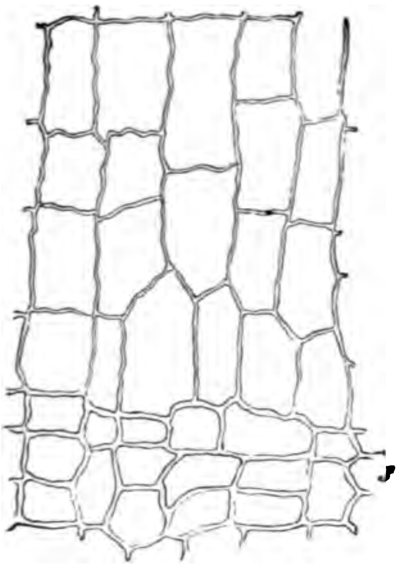


FIG. 174.

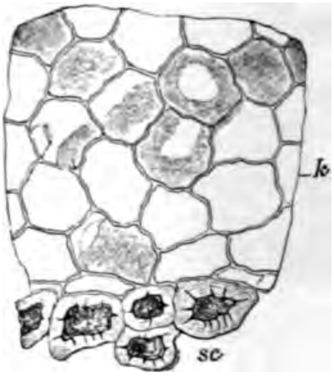


FIG. 175.

FIG. 174. Oak Cork in Cross-section. (T. F. HANAUSEK.)
J boundary of previous year's growth; cells smaller with thicker walls.

FIG. 175. Oak Cork in Longitudinal Section. (T. F. HANAUSEK.)
k cork cells (cross-section), some showing walls in surface view; *sc* sclerenchyma cells.

We will now consider the chemical composition of the suberized cell walls, to which cork owes its extensive application as a material impermeable to air [1] and liquids. Experience has shown that cork is resistant different results and has found that the suberin lamella contains no cellulose, the red-violet obtained by successive treatment of cork cells with potash and chlorzinc iodine being due, not to cellulose, but to phellonic acid. Furthermore GIBSON assumes that primary fat is not present in cork, since fat solvents remove only traces of fatty material; glycerine is, however, certainly present, but its combination is not yet definitely known.

---

[1] According to KAMERLING (Bot. Centb. 1897, **72**, 54–56), cork has a relatively high permeability to air. WIESNER and MOLISCH (Bot. Centb. 1889, **39**, 214–215) state that the vegetable cell membrane does not permit the filtration of gases under pressure; ". . . on the other hand, the suberized and lignified cell membrane permits air-dry gases to pass

We have already learned in the chapter on subterranean organs that the **Endodermis** is a cell layer separating the peripheral part of an underground axis from the central cylinder. As v. HÖHNEL has shown, the membrane of this separating cell layer is like that of true cork cells in structure; accordingly its physiological function *mutatis mutandis* is the same.

As regards the **Cuticle**, to which reference has been frequently made, it is commonly assumed that this consists of a suberized lamella; if between the cuticle covering the epidermal cells and an inner cellulose layer of these cells there are one or more, usually less strongly "suberized," layers, these are known as cuticular layers. In opposition to the theory that the cuticle owes its origin to a process of suberization, VAN WISSELINGH,[1] who distinguishes sharply between cutinization and suberization, has contended that even as regards their manner of formation cutin and suberin are fundamentally different. The cork lamella is formed on the inner side of the phellogen cell (which, however, according to the investigations of v. HÖHNEL, is not correct), the cuticle, on the outer membrane of the epidermal cells. Since the cuticularized thickened layers are separated from the cell contents by cellulose lamellæ, the cutin (in case it originates in the cell contents, which VAN WISSELINGH has not proved) must pass through these cellulose lamellæ; the cork lamellæ, however, are always in immediate contact with the protoplasm (contrary to the statement of v. HÖHNEL). Cutin does not contain phellonic acid. After maceration in chromic acid, the membranes, with one exception, on treatment with iodine in potassium iodide are colored brown or yellow. Probably various acids which have little similarity as regards deportment toward reagents and structure with those obtained from cork lamellæ play an important rôle in cutin.

---

[1] Over cuticularisatie en cutin (Verhandelingen der Koninklijke Akademie van Wetenschappen te Amsterdam). Tweede Sectio. Deel III, 1894, No. 8. Abstract in Bot. Centbl. 1896, **62**, 234.

OAK BARK.

Of great importance for the tannin industry are the trunk and branch barks of various trees, since they not only contain a sufficient amount of tannin, but are also easily obtainable and in abundance. Of importance for the European industry[1] are the barks of central European species, especially the tan-bark oak (*Quercus sessiflora* Salisb.) and the common or British oak (*Q. Robur* L. = *Q. pedunculata* Ehrh.); in addition, bark is gathered from the bitter oak (*Q. cerris* L.) and the black oak (*Q. lanuginosa* Lam. = *Q. pubescens* Willd.). The two species first named are grown in special forests and yield an excellent product which up to the twenty-fifth year is free from rough bark, at least in places.

The following sorts,[2] differing as to the age and method of preparation, are distinguished: (1) Smooth Bark from trunks 10 cm. in diameter; (2) Fissured Bark from trunks 10–20 cm. thick; (3) Raw Coarse Bark; (4) Cleaned Coarse Bark. The first two sorts are divided into three grades according as they are obtained from the bottom, middle, or top of the trunk; that from the bottom is the richest in tannin. Smooth bark of good quality should not be cracked or have a rough outer bark; it should have blotches (lenticels) and a good luster. The outer surface is silver-gray, the inner surface light brown or brown-red, longitudinally striate; the bark shows strap-shaped fibers on the fractured surface, is tough, almost odorless (when moist, with a tan-bark odor), in taste strongly astringent. The cut surface is colored dark blue or black-blue by a very dilute solution of iron chloride. Smooth oak bark contains 8.5–19.02 per cent of tannin, 1.59 per cent of gallic acid, 58.23 per cent of crude fiber, 8.33 per cent of malic acid, sugar, and extractive matter, 6.31 per cent of resin and fat, 2.34 per cent of oak red, and 6.77 per cent of pectic acid. Oak bark (mostly mixed with spruce bark) is one of the best tannin materials for thick, heavy kinds of leather. It comes into the market in band-shaped or channelled pieces or else as the shredded or bruised bark.

---

[1] The number of tan barks is very great and it may be said that each country works up its own native barks. Southern European, Oriental, and North African oaks, also African and North American conifers, yield tan barks (see v. HÖHNEL: Die Gerberrinden, 31–87). Willow bark is of importance in Russia. The exposition at Vienna brought to our notice numerous exotic barks, of which those of the following species deserve mention: *Weinmannia glabra* L. fil., *Malpighia punicæfolia* L., *Acacia decurrens* Willd., *Rhizophora Mangle* L., etc. The bark of mangle colorado (*Rhizophora Mangle* L.), first described by the author (Die Gerbematerialien Venezuelas. Ztschr. allg. Österr. Apoth. Ver. 1876, No. 24), appears at the present time to have attained importance.

[2] v. HÖHNEL: Die Gerberrinden. Berlin, 1880. *Idem:* Wiesner's Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1900, **1**, 742. LUEGER: Lexikon d. ges. Technik. Gerbstoffe. 2. Aufl. **4**, 400. 404.

MICROSCOPIC STRUCTURE.[1]

It is recommended to study first young barks; after the general structure and the form of the individual tissue elements are sufficiently understood, older rough barks can be taken up. Transverse and radial-longitudinal sections are cut, cleared with potash, and mounted in glycerine, arranging them for convenience so that the outer sides are together. At the periphery, we see the **Periderm**, or outer bark (Fig. 176, *k*). The cells of the first few rows are so strongly flattened tangentially that the lumens appear as narrow brownish streaks, while the walls are light yellow. Here and there this part of the periderm is ruptured, the torn ends are directed outward, and in the gap are groups of small rounded cells. This is the structure of a typical **Lenticel**, or bark pore (p. 270). The cells of the following periderm layers are somewhat less compressed and contain deep-brown contents. The periderm is best distinguished by the well-known radial arrangement of the cells (see Figs. 176 and 177). Beneath the periderm we find a less distinct, very thin plasma-rich cell layer of a gray color, forming the mother tissue of the periderm. This is the **Phellogen**. In many barks the phellogen forms on its inner side a permanent tissue, the **Phelloderm**,[2] which increases the thickness of the middle bark on its outer side. We find such a phelloderm in oak bark immediately beneath the phellogen in the form of 2–3 layers of true collenchyma cells, which are characterized as such by the strong thickenings at the angles; in cross-section these are rather strongly elongated tangentially, but in radial-longitudinal section they are more nearly rounded-rectangular or rounded-quadratic (Fig. 176, *c*); their light-yellow walls are characterized by a brilliant luster. As far as has been observed only three cell rows of this collenchymatous phelloderm are as a rule developed; in places, however, where owing to diversion of the branches the number of layers varies up to 20,[3] so-called pressure spots are formed. The phelloderm passes almost immediately into the **True Parenchyma** (cortex, bark parenchyma, primary bark, middle bark); this forms a rather broad layer and consists of thick-walled cells, varying little in size, which are only slightly elongated in cross-section and are almost round in longitudinal section (Fig. 176, *r*).

---

[1] Moeller, Anatomie der Baumrinden. Berlin, 1882, [illegible].

[2] F. Kuhla, Ueber die Entstehung und Verbreitung des Phelloderms. Bot. Centb. 1807, 71, [illegible] J. E. Weiss: Beiträge zur Kenntniss der Korkbildung. [illegible]

[3] Kuhla, [illegible]

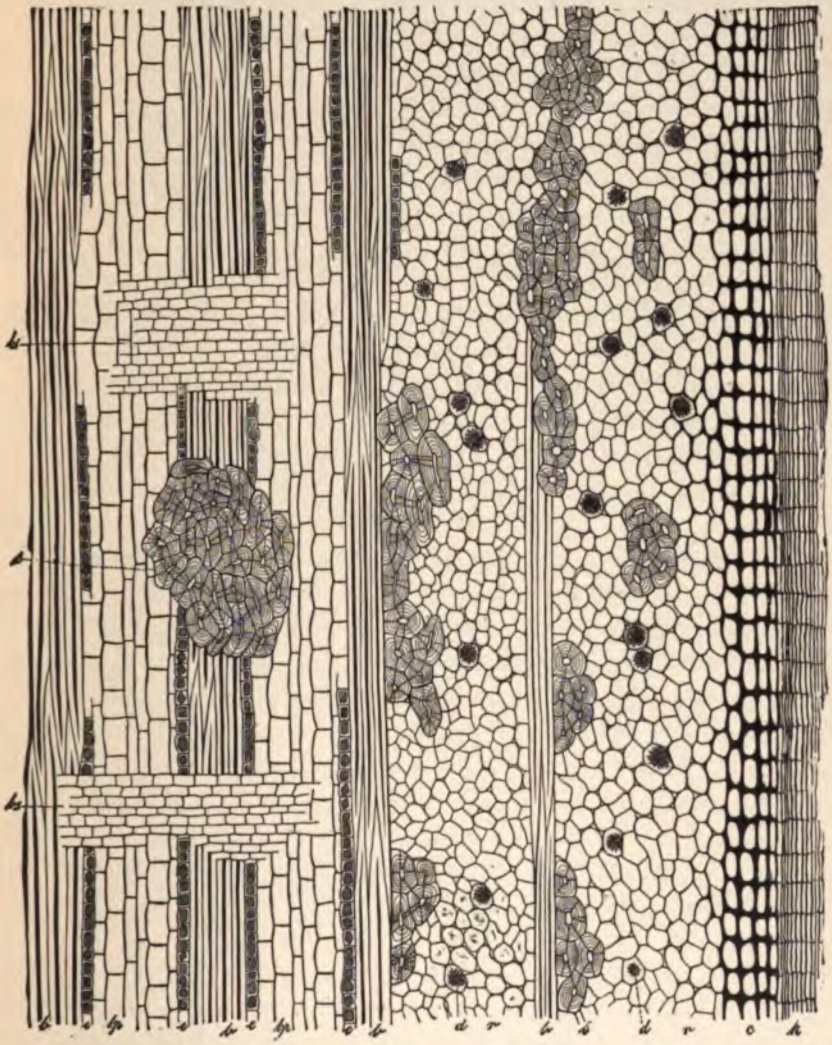


FIG. 176. Radial-longitudinal Section of Oak Bark. (LUERSSEN.)

k cork; *c* collenchyma; *r* bark parenchyma; *d* crystal rosettes; *s* stone cells; *b* bast fibers; *e* crystal fibers; *bp* bast parenchyma; *bs* medullary rays.

These cells in the fresh bark contain calcium oxalate together with chlorophyl grains; the former appears at first only as large crystal rosettes, one of which is formed in each cell. Many cells contain in addition brown masses. But not all the cells of this layer possess this character. We find groups or nests of them changed into **Sclerenchyma Cells** (stone cells) which are beautifully stratified, richly pitted, and so strongly thickened that the lumen is reduced to a very small size (*s*). The form of these sclerenchyma cells is mostly regularly rounded or somewhat elongated, less often cubical, also with coves. In thin sections they are almost colorless. Not rarely individual cells in the parenchyma about them contain a large rhombohedron-like simple crystal.

If we follow the bark inward, our attention is attracted by a remarkable structure in the form of a narrow closed zone separating, like a wall, the portion of the bark already described from the inner portion. This zone, designated by TSCHIRCH [1] the **Mixed Sclerenchyma Ring** and, for short, the **Mixed Ring**, is seen to be made up of cells of three kinds, which, however, can be clearly distinguished by the beginner only in longitudinal section. In cross-section he will recognize the numerous closely united sclerenchyma cells by their thickened, stratified, and porous walls. He will also notice smaller, mostly rounded groups of sharply angular, polygonal (in cross-section) cells, with walls so strongly thickened that the lumen is reduced to a mere point; these, after studying the textile fibers, will remind him of cross-sections of bast fibers, which, indeed, they are. As the longitudinal sections show, long strongly thickened bast fibers (Fig. 176, *b*) are inserted between the groups of sclerenchyma cells, forming what are known as simple bast bundles (see summary in the section on rattan, p. 258). Longitudinal sections also show that these fibers are accompanied by chambered or partitioned tubes, each compartment containing a single monoclinic crystal; these are the so-called **Crystal Fibers**. The term "mixed sclerenchyma ring" is then self-explanatory.

Inside of this zone the appearance is somewhat varied. We find, as it were, duplicate but disconnected mixed rings; there are large and small groups of sclerenchyma cells accompanied by bast bundles and crystal fibers, and the further inward we go the more numerous are the bast bundles.

The **Bast Fibers** are up to 25μ broad, several hundred micromillimeters long (according to A. VOGL[1] over 600μ), somewhat bowed and knotty, mostly pointed, "on the sides provided with numerous tooth-like notches, the impressions of the small clinorhombic single crystals of calcium oxalate contained in the numerous crystal fibers which form a network about the bast-fiber bundle."

---

[1] Angewandte Pflanzenanatomie, 389.

Now we will glance at the parenchyma in this part of the bark as seen in cross-section. We notice how in certain places the parenchyma cells gradually lose their tangential elongation or general isodiametric form and become radially elongated; finally we see such cells arranged in one or two radial rows penetrating the inner part of the bark and forming stripes or rays. These cell rows are the **Bark Rays**, the analogues of the secondary medullary rays of wood. The tissue between the bark rays is the phloem of the vascular bundles, also known as the bast because of the presence of bast fibers. It consists of bast-fiber bundles, bast parenchyma and sieve tubes, of which the last, especially in dried bark, are almost never distinctly seen in cross-section. In longitudinal section we see that the sieve tubes are thin-walled, narrow, elongated tubes, about the breadth of the bast fibers, with lateral as well as transverse sieve plates.

If we follow the course of a bast ray inward, we will notice that a more or less four-cornered bast-fiber bundle is followed by a section of bast parenchyma and this in turn by another bast-fiber bundle and so on in regular alternation. Again a highly striking regularity of arrangement of another kind is also noticeable. Since in each bast ray there are formed at the same time and in the same position bast-fiber bundles and bast parenchyma (with sieve tubes), the bast-fiber bundles of the individual rays appear to be arranged in a tangential row and, owing to the regular alternation of the two phloem constituents, the inner bark must show a panelled or stratified arrangement, which is highly characteristic of the bark and is distinctly evident under a lens.[2] Also in this part of the inner bark many parenchyma cells contain oxalate rosettes. In radial longitudinal section the bark rays cross the bast bundles; the cells of the former are in this section somewhat regularly rectangular.

On the inner side the bark ends at the cambium layer which, as is well known, forms the xylem on the inner, and the phloem on the outer, side. It is now clear why the whole bark, in the technical sense (e.g., willow bark) consisting of outer, middle, and inner bark, especially that of branches, can be more or less easily separated from the wood; the cambium layer which unites bark and wood is not ruptured by this separation, but remains attached to the bark.

---

[1] Arzneikörper, 1892, 224.

[2] MOELLER (*loc. cit.*) describes the structure as follows: "Narrow bands of bast fibers, mostly only 2–4 rows broad, alternate with layers of soft bast 2–3 times as broad, the latter often being separated again into parenchyma cells and sieve tube layers."

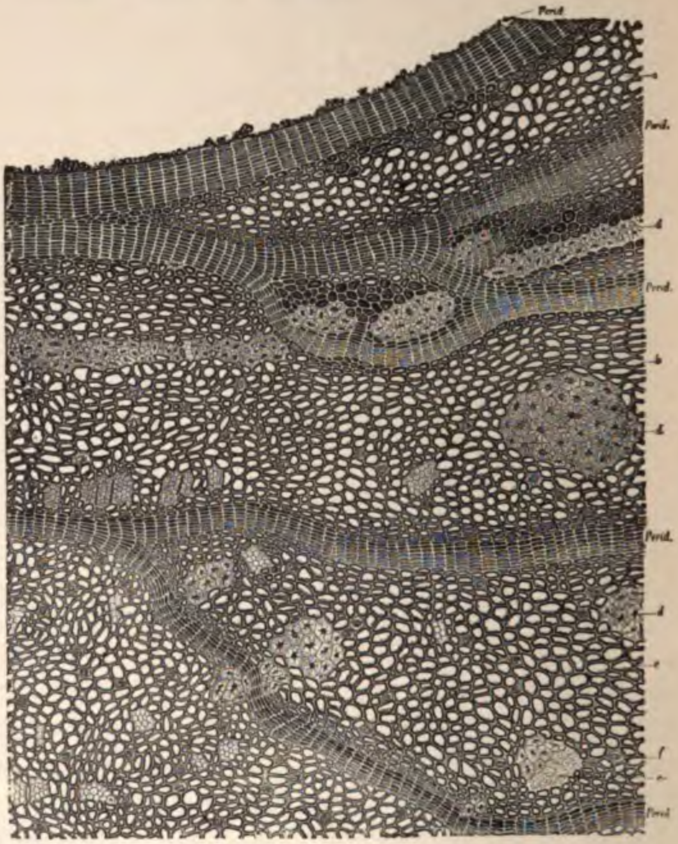


FIG. 177. Cross-section of Outer Part of Secondary Bark of English Oak (*Quercus Robur*). (KNY.)

a, *b*, *c* bark- and bast-parenchyma and sieve tubes; *d* stone cells; *e* bast fibers; *f* cells with calcium oxalate; *Perid.*, periderm zones forming inner boundaries of bark scales.

If the structure of old oak bark (Fig. 177) is compared with that above described, important differences in the parts of the outer and middle bark will be noticed. The outer surface shows a striking difference, even to the naked eye; instead of the gray, smooth bark we see a cracked and fissured rough bark. On laurel and orange trees and most of the upper branches of the birch we find the bark smooth and free from cracks and fissures; on these no rough bark is formed. Since the bark, as well as the wood, is continually adding on new zones due to the activity of the cambium layer, the tissues outside of the secondary bark, namely periderm and bark parenchyma, must likewise increase in circumference and therefore in volume. The periderm is able to keep pace with this growth owing to its independent cambium, the phellogen. As for the bark parenchyma, which at first broadens by the tangential extension of its cells, this also experiences an increase in the number of cells owing to the activity of the phellogen, which may form new cells on its inner side, thus forming the phelloderm already described (Fig. 177). In most trees, however, this enlargement is insufficient; the periderm can not keep pace with the growth in circumference of the tree and it loses its meristematic character, but there is formed in the deeper layers of bark a new periderm layer (Fig. 177, *Perid.*) which cuts off the layers of the middle bark lying without it thus separating them from the living tissues and leaving them to die. These outer dead layers constitute the rough bark. The manner of separation of this rough bark in plates, scales, etc., is characteristic of the species. Spruce has a bark with pronounced plates. Fig. 178 shows us a lens view of the periderm layers which adjoin narrow lens-shaped pieces of bark—the bark scales. Oak bark forms coarse fissured, very rough, angular pieces.

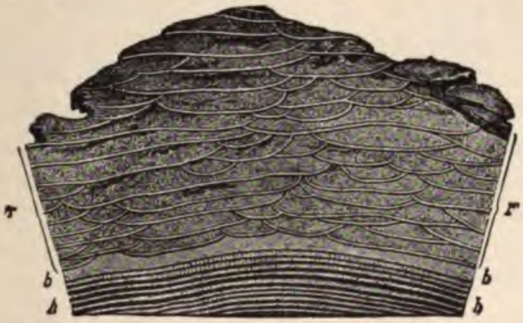


FIG. 178. Bark Scale of Pine. (WILHELM.)
r dead bark; *b* living bark; *h* wood.

Since rough bark is poor in cell contents, it has, as a rule, no industrial value;[1] bark freed from the rough cork is known as scraped or cleaned bark.

---

[1] According to v. HÖHNEL (Gerberrinden, 1880) the bark of the hemlock (*Abies Canadensis*

Now that we have learned the structure of a complete (economic) bark, we can summarize the relation of this bark to the vascular bundles and the remaining stem tissues as follows: The primary (middle) bark, the bark rays, the primary medullary rays of the wood, and the pith are the remains of the ground tissue,[1] in which are contained the vascular bundles. The inner bark, or the bast rays, consists of the phloem of the vascular bundles.

QUILLAI BARK.

Quillai bark is obtained from a tree-like rosaceous plant (*Quillaja Saponaria* Molina), a native of Chile, and is extensively used in scouring colored fabrics, wool, etc. It owes its value to its high percentage of glucosides of the saponin group (see soapwort, p. 269). Since the commercial product as it reaches our market consists largely of secondary bark, the worthless outer bark having been in large part removed, we can make a microscopic study only of the tissues of the inner bark. The product nevertheless furnishes the beginner with an excellent material in which he can examine the extraordinarily distinctly developed sieve tubes with large sieve plates. The sieve tubes of most barks are usually studied with difficulty; those in the primary phloem are so shrivelled and compressed that they (as well as the companion and cambiform cells) appear in cross-section as indistinct, thick streaks which show no details of structure and bring to our notice a special form of tissue known as **Horny Prosenchyma** or **Ceratenchyma.**[2]

The commercial product[3] consists of flat, very hard, various-sized, outwardly brownish-yellow or grayish plates up to 8 mm. thick, which break with a very coarsely laminated fracture, and show under a lens numerous glistening crystals. The cross-section, similar to oak bark, presents a checkered appearance due to the very regular arrangement of the large bast-fiber bundles in both radial and tangential directions. This concentric stratification of the bark, as noted by J. MOELLER, is not evident

---

Michx.) is characterized by the fact that the chief seat of the tannin is the rough bark and not the living bark. Again *Scorza rossa*, a tannin material of the Mediterranean region, is the rough bark of the Aleppo pine (*Pinus halepensis* Desf.).

[1] The original division into dermatogen, etc., is described on p. 290.

[2] For a description of this tissue, together with a bibliography, see TSCHIRCH: Angewandte Pflanzenanatomie, 346.

[3] v. HÖHNEL: Wiesner's Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903, **1**, 765. MOELLER: Anatomie der Baumrinden, 368. *Idem:* Realenzyklopädie d. ges. Pharm. 2. Aufl. **10**, 538. VOGL: Arzneikörper, 249. WIESNER: Rohstoffe. 1. Aufl. 405.

on microscopic examination owing to the appearance of smaller bundles distributed among the large ones.

The reason why the checkered arrangement is so regular in radial directions is found in the presence of straight medullary rays of almost uniform breadth, which are usually four (according to J. **Moeller** up to six) cells broad and vary in height up to 20 cell rows. The walls of the medullary cells are very thin. The bundles of bast fibers occurring in the bast rays are not infrequently divided into two or three parts by rows of parenchyma cells which resemble in a certain degree secondary bark rays. The bast fibers are bowed or knotty, very thick-, occasionally porous-walled, with here and there broadened lumens (Fig. 179, *bf*). Adjoining the bast-fiber bundle are longitudinally elongated thin-walled

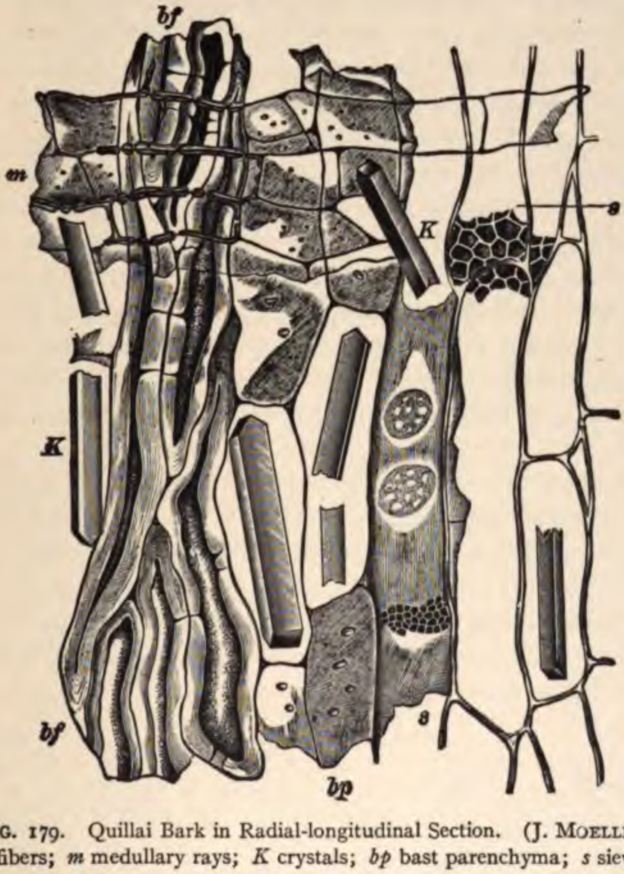


Fig. 179. Quillai Bark in Radial-longitudinal Section. (J. Moeller.)
bf bast fibers; *m* medullary rays; *K* crystals; *bp* bast parenchyma; *s* sieve tubes.

parenchyma cells containing the large **Crystals** of calcium oxalate which are so characteristic of quillai bark. These crystals are simple prisms or swallow-tail twins, mostly 100–160μ, rarely up to 200μ long (K). The bast parenchyma contains thin-walled rather large cells, individuals or small groups of which, in the immediate neighborhood of the bast fibers, are transformed into **Sclerenchyma Cells.** In a radial section before me I find the following structure: Between two bark rays of about equal height and situated very close together, with the well-known radially-elongated four-sided cells, lies a parenchyma layer at first of one, later of two cell layers, the cells of which are rounded-elongated and somewhat elongated radially, therefore strikingly different from the bark ray cells. This layer starts at a bast-fiber bundle (with one cell layer) and at the other end passes into the bast parenchyma. Enclosed in this group are five cohering, very strongly thickened, laminated pitted sclerenchyma-like elements. This arrangement is regularly repeated, although the number of thickened cells may vary. These latter are not stone cells, but diagonally arranged, bowed bast fibers of small bast bundles, which are so cut in longitudinal section of the bark that they are almost in cross-section.

Both in transverse and longitudinal section, we are struck by the beautifully latticed sieve plates of the sieve tubes. A well-cleared section shows the sieve tubes with their broad plates in considerable numbers.

Contained in the parenchyma cells are starch grains and colorless lumps which dissolve in water to a colorless solution and in concentrated sulphuric acid first to a yellow, then to a red, and finally to a violet solution (ROSSOLL, see p. 270).

V. FINAL COMMENTS.

In the section on rattan we gained a general idea of the structure of compound strands or vascular bundles and learned the significance of the terms xylem, phloem, cambium, etc. Our study of the histology of turmeric gave us an opportunity to learn the distinction between collateral, concentric, and radial vascular bundles.

The origin of vascular bundles may be studied at the apex of a stem, at the so-called growing point, where we may distinguish three formative, or meristematic, tissues, namely the **Dermatogen,** the **Periblem**, and the **Plerom.** From the first is derived, for the most part, only the epidermal tissues (also simple bundles), from the periblem the primary bark, from the plerom the vascular bundles, the medullary rays, and the pith. In the monocotyledons the first formed vascular bundles are distributed throughout the stem; in dicotyledons and conifers they are arranged in a ring. In order that a stem increase in diameter, it is necessary that the primary medullary rays increase in length and a part of the same perform the function of a cambium, thus connecting the cambium of neighboring vascular bundles. This tissue is known as **Interfascicular Cambium.**[1] This explains the formation of a closed ring (thickened ring) from the cambium (p. 259). Between the first formed vascular bundles are also interposed new bundles, the xylems of which constitute the **Interfascicular Wood**. In the woody stems of dicotyledons (see Figs. 115 and 137) a homogeneous woody structure is formed in this manner in which the medullary rays are distinct, but a sharp demarkation of the xylem of the individual bundles is no longer evident.

In the case of herbaceous stems of the dicotyledons, either only the original vascular bundles are present or else a closed wood cylinder entirely free from medullary rays is developed; finally interfascicular cambium layers may also make their appearance. WIESNER,[2] basing his distinctions on these characters, describes the following six types of normal dicotyledonous stems: (1) herbaceous stem without interfascicular cambium; (2) herbaceous stem with interfascicular cambium; (3) woody perennial stem becoming thickened by further growth of the primary vascular bundles; (4) woody perennial stem becoming thickened by further growth of the primary and interfascicular bundles; (5) woody stem with closed wood cylinder, the secondary wood of which no longer shows evidence of division into xylem bundles, but is provided with medullary rays; (6) herbaceous stem with closed wood cylinder but no medullary rays.

We see from this interesting classification that the wood of our dicotyledons belongs to type 5, but that this kind of structure is not the only one in the stem of dicotyledonous and gymnospermous plants.

As is well known the vessels[3] serve to conduct water, the sieve tubes with the enclosing conducting parenchyma, to translocate plasmic material, or, in other words, to conduct the nutritive material already formed to all parts where it is needed for building up organs or for replacing used-up material, while the excess is deposited in peculiar reservoirs or store-rooms. The mechanical elements such as the libriform fibers and the bast fibers of the phloem serve definite purposes in strengthening the stem; they must give the stem rigidity or tensile strength and the root strength to resist pressure.

---

[1] See WIESNER: Anatomie und Physiologie der Pflanzen, 1898, 167.

[2] *Ibid.*, 170.

[3] Often the pits of vessels and tracheids are seen, by proper focusing, to be crossed by a line or even by two crossing lines (see p. 186; Fig. 124). The single lines are explained by the fact that one of the orifices of the pore canal is not round but in the form of a slit, thus appearing as a narrow streak. If the orifices on both sides are thus constricted, the slits being at right angles to each other, they form two crossing streaks.

Since the vascular bundles (veins or nerves) of leaves proceed from the stem and the vascular bundles of the dicotyledons are common to both leaf and stem, each annual growth of wood represents nothing else but the physiological activity of the entire leaf system in one vegetative period. If, however, an additional replacement of leaves takes place in the same growing season, due, for example, to a frost in May or the appearance of leaves in autumn, there must be formed a second annual ring, and the wood shows two rings for the same growing season.

As a rule the second ring is easily recognized by its smaller thickness and the sparingly developed vessels. If the vascular bundles are considered only from the physiological standpoint and those elements are disregarded which perform the mechanical functions (libriform fibers of the xylem and bast fibers of the phloem), the composition of a completely developed vascular bundle may be elucidated by the following scheme:[1]

1. Xylem (Wood, Hadrom[2]).
    - (*a*) Vessels,
    - (*b*) Tracheids, } Organs for conducting water.
    - (*c*) Wood Parenchyma: Partly for conducting water and plasmic materials; partly for storing up the latter.
2. Phloem (Leptom, Bast).
    - (*a*) Sieve Tubes with accompanying cells,
    - (*b*) Cambiform Cells (cambium converted into permanent tissue), } Organs for conducting plasmic materials.
    - (*c*) Phloem Parenchyma: For conducting soluble plasmic materials.
3. Parenchyma Sheath: Also for conducting plasmic materials.

---

[1] Tschirch: Angewandte Pflanzenanatomie, 359.

[2] As originally used by C. v. Nägeli, the xylem included also the libriform fibers and the phloem of the bast-fiber bundles.

VI. PRACTICAL EXAMPLES.

1. Among the problems which the technical microscopist is called upon to solve, the determination of the species of wood from which a wood-pulp paper is made is of especial importance. Coniferous woods are most commonly used for making wood pulp, less often broad-leaved woods, especially aspen (trembling poplar, *Populus tremula* L.).

The following example, although not involving the examination of paper, is of interest in this connection.

A piece of a Swedish match dyed a red color and a piece of white (uncolored) match were both supposed to be made of the same wood, namely, poplar. Examination showed that the white match was really poplar, but that the red one was spruce. Owing to the dye, the species could not be easily recognized by the external appearance, at least with the naked eye.

Poplar wood generally has marked microscopic characters. We find in paper pulp (Fig. 180, *B*) first of all numerous fibers which are strongly thickened and show various mutilations. These are the libriform fibers of poplar.

If we examine a radial section of poplar as to its vessels and medullary rays we note as follows: The vessels have bordered pits with slit-like openings and polygonal, or less often rounded, outline, but no scalariform perforations. In paper stock the pits, owing to swelling, etc., are somewhat enlarged and the chamber is indistinct. The medullary rays consist of two kinds of cells, analogous to those of various conifers; the outer cells have rounded pits, the inner have very small pores and display an irregularly outlined thickening; some of the rays, however, have cells with only the rounded pits.

With the aid of these guide elements poplar may be detected with certainty in paper.

Of quite different origin is American white wood from *Liriodendron tulipifera*, which has been used to some extent for paper pulp (Fig. 180, *A*). Diagnostic elements are the large vessels and joints of vessels, the bordered pits of which resemble narrow slits, while the chambers of the pits are more indistinct. The ends of the vessels are blunt and usually show quite distinct, scalariform perforations (*lp*). In addition we find elongated parenchyma cells with strongly thickened walls and numerous small single pits which are accumulated like the holes of a sieve, particularly on the narrow ends (*m'*), also similar cells with large round pits (r which are mostly arranged in three rows and are often so close togeth that the cell walls present the appearance of a delicate network.[1]

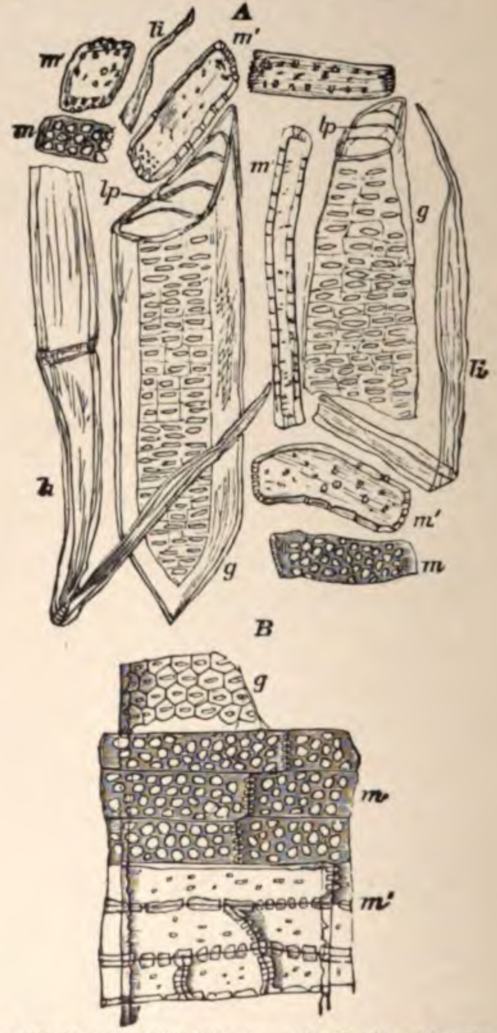


FIG. 180. **Elements of** White Wood (*Liriodendron tulipifera*) and Poplar (***Populus tremula***). (T. F. HANAUSEK.)

A elements of white wood from paper.—*B* radial section of poplar, showing medullary ray with a part of a vessel in the background; ***g*** vessel with ***lp*** scalariform perforation; ***m*** and ***m'*** medullary cells; ***li*** libriform fibers.

2. Samples of a dyewood, branded Cuban fustic, were submitted by

---

[1] See LITSEHAUER: Amerikanische Aspenzellulose. Zentb. Papier. 1905, **26**.

a commercial house. Even by a cursory observation it could be seen, from the presence of annual rings, the greenish-yellow color, and the brilliant luster, that the branding was entirely false and that the sample was not a tropical wood but was young fustic. The blood-red color with potash, the presence of numerous pores (or vessels) in the spring wood, and especially the microscopic appearance (numerous spiral tracheids) showed that the wood was certainly young fustic from *Cotinus*.

3. The light-brown wood of a cigar-box was submitted for identification. A fresh cross-section furnished evidence that the wood was dyed, since the original light color was evident in the interior notwithstanding the marked thinness of the wood; furthermore, it was obvious that the material was a soft wood. The medullary rays, which were visible only under a lens, were very fine, somewhat uniform; the vessels were exceedingly fine and numerous, and were distributed through the annual rings. The wood was pronounced to be linden, and the identification was made absolutely certain by a microscopical examination.

4. Not infrequently it is asked whether the tree from which a given sample of wood was obtained was felled in summer or in winter. Practical men are generally of the opinion that wood cut in winter is the more durable. This question can not easily be answered with certainty.

It is often stated that the tissues for storing reserve material in winter wood contain starch; this, however, is not true of many woods since, in November they begin again to translocate the starch, after which very little or none of this substance can be detected. If a large amount of starch is found in the medullary rays and wood parenchyma, it may be concluded that the wood was cut in the late autumn if not later. (See Mer's statements, p. 211.) The lesser durability of timber felled in spring and summer, which is especially manifested by its susceptibility to dry rot (*Merulius lacrymans* Fr.), should be attributed partly to the larger content of nitrogenous substances; the presence of a greater amount of soluble ash constituents in April than in winter also promotes the growth of the fungus, since the latter is in especial need of mineral matter.[1]

5. The identification of sawdust as an adulterant of powdered foods, including spices, is not so difficult if the wood is a conifer. If, however, the sawdust is from a broad-leaved wood it is recommended to compare it with those used for building and veneering, such as, for example, oak, beech, linden, ash, and walnut.

---

[1] See SORAUER: Handbuch der Pflanzenkrankheiten. Berlin, 1886, 2, 259, 261.

A sample of ground cinnamon was found to be adulterated with beech sawdust. The elements shown in Fig. 132 furnished sufficient evidence for the identification of this material. Since the plan of this book does not permit an exhaustive microscopic description of all these species, it need only be remarked that the microscopist who has carefully studied the foregoing sections on woods is prepared to investigate all woods of normal structure. The identification of a given species is then a matter of comparison.

6. A sample of fig coffee was found to contain numerous fragments of a brownish, very soft, elastic material. Sections cut after attaching the fragments to a cork showed that the material was common cork. The presence of this impurity may be explained by the fact that holes had been repeatedly bored in the box in which the goods were packed, to withdraw samples, and that each time the holes had been closed with cork stoppers.

7. Various ground spices are adulterated with red sandalwood, added possibly to improve the color. Fragments of this wood are recognized by the brick-red color, the red solution of the coloring matter obtained on treatment with potash, the libriform fibers, and the pieces of vessels with numerous bordered pits.

CHAPTER V.

LEAVES.

THE study of leaves used in the arts with reference to their identification as found on the market, requires first of all a consideration of the external morphological characters. These characters, especially the course of the nerves or veins and of the ends of the nerves, are also of service in the examination of the coarsely powdered leaves. The significance of the venation at the borders of the leaves and in the teeth has been brought into notice of late years chiefly through the investigations of TSCHIRCH [1] and H. VIRCHOW.[2]

Finely powdered leaves, on the other hand, can be identified only by the microscope. A microscopic investigation of a leaf for this purpose should proceed along the following lines: First of all, in order to gain a general idea of the structure, thin cross-sections are prepared with a razor holding a piece of the leaf between two flat pieces of cork during the cutting; if the leaf is dry, it is recommended to soften it somewhat by previous soaking in water. In many cases it suffices to wrap several pieces of the softened leaf around the outside of a round cork stopper and cut through these pieces toward the cork. The cross-section should include not only the leaf mesophyl but also the principal nerve (if such is present) and several secondary nerves.

Cross-sections show whether the leaf is bifacial, isolateral, or centric.[3] They also serve for the study of the vascular bundles or nerves. An investigation of the cell contents (chlorophyl grains, starch, calcium oxalate, essential oil in oil cells, etc.) goes hand in hand with that of the tissues. Chloral hydrate is of great value in clearing the histological elements. In addition to the characters already named, cross-sections show the structure of the stomata, of the epidermal cells with their cuticle, and of the hairs which are frequently present, also the method of insertion of the hairs in the epidermis. Surface mounts of both epidermal layers are next prepared, either by stripping off the " skin " from the soaked leaf with the aid of a scalpel, or else, in a hasty examination, by squeezing small fragments under the cover-glass. Not only the form of the epidermal cells should be noted, but also the number and distribution of the stomata, glandular formations, etc. Finally the anatomical study is completed by an examination of the vascular bundles in longitudinal view.

---

[1] TSCHIRCH u. OESTERLE: Anatomischer Atlas. Table 3, p. 9, and Table 19, p. 73.

[2] HANS VIRCHOW: Ueber Bau und Nervatur der Blattzähne und Blattspitzen mit Rücksicht auf diagnostiche Zwecke im Gebiete der Pharmakognosie. Arch. Pharm. 1896, **234**, Heft 2.

[3] These terms are defined on p. 29.

A cross-section of a typical bifacial leaf is shown in Fig. 24, another (hemp leaf) with various forms of trichomes in Fig. 47. In Fig. 130 we see a lysigenous oil cavity in the mesophyl, the contents of which give the leaf the appearance to the naked eye of being perforated. We find in these cuts the epidermis of the upper and lower sides, the palisade cells, and the spongy parenchyma; we have previously learned the most important functions of the leaf and its tissues (p. 29). It remains only to describe the peculiar openings in the epidermis. The **Stomata** are formed by two usually crescent-shaped cells, known as **Guard Cells** (Fig. 181, *S*), between which is an aperture (**Pore**) of variable size, opening into the **Respiratory Cavity** (*AH*). Under certain conditions the aperture closes.

The guard cells in the *Gramineæ* and *Cyperaceæ* are of an anomalous form; they are elongated longitudinally and peculiarly thickened (Fig. 85, *sp*). The cells immediately adjoining the guard cells of a stoma are known as **Accompanying Cells** (Fig. 181, *a* and *b*; see also Sumach, Fig. 189). A more complete idea of the structure is gained by studying the cross-section (Fig. 181, lower cut). The guard cells[1] in cross-section are often quadrilateral or rounded, less often entirely irregular. " These irregularities are due chiefly to great variation in the thickening of the outer border and in a lesser degree of the inner border. Since without exception these are made up either of the cuticle alone, or of this and a cuticular layer, I have designated them cuticular borders " (TSCHIRCH). The form of the lumen is also remarkable; in cross-section it has the shape of an isosceles triangle of which the apex is at the aperture and the base forms the wall separating the guard cell from the accompanying cell. This separating wall is very thin and forms, as it were, "a membranous joint" which plays an important part in the opening and closing of the stoma. The stomata open in the light and close in the dark, provided sufficient moisture is at the disposal of the plant; in a drought they remain closed. They are, then, automatic ventilators for regulating the exchange of gases.

---

[1] See the exhaustive treatment of this subject by TSCHIRCH: Angewandte Pflanzen anatomie, 431. SCHWABACH: Entwicklung etc. Ber. Deutsch. Bot. Gesell. **20**, 1.

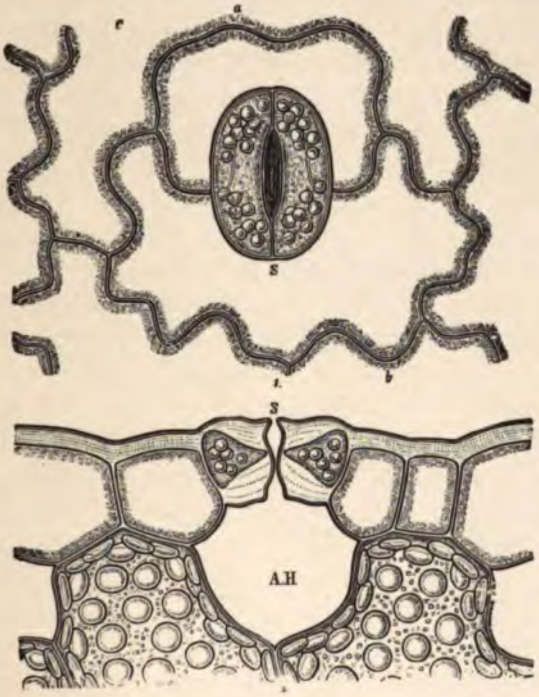


FIG. 181. Thyme Leaf (*Thymus Serpyllum* L.) Epidermis and Stoma. (KNY.)
1 surface view: *C* epidermal cells; *S* stoma; *a* and *b* accompanying cells.—*2* cross-section showing, beneath the epidermis, parts of two cells with chlorophyl grains: *S* stoma; *AH* respiratory cavity.

Water Stomata or **Water Pores** are special forms of stomata. These discharge liquid water, and their cells do not have the power of closing.

As regards the diagnostic significance of stomata, TSCHIRCH[1] states that they play an important rôle in applied vegetable histology. "Their form and distribution are still distinctly recognizable in the powder, since the epidermal cells have great coherence and the epidermis with its stom may often be found in large sheets. Oftentimes the form, size, and d tribution of the stomata are called into service in diagnosis." We sh see that the species of sumach can be determined readily and with certain by the stomata.

---

[1] Angewandte Pflanzenanatomie, 441.

SUMACH.[1]

This product, used in the tanning and dyeing industries, consists o the dried and ground leaves of several species of *Rhus* and commonly contains, sometimes in large amounts, petioles, fragments of young branches, and even flowers. The product gathered in the Mediterranean region and employed exclusively in Europe is from the Sicilian sumach (*Rhus Coriaria* L.) and Venetian sumach (*Cotinus Coggygria* Scop. = *Rhus Cotinus* L.; see young fustic, p. 246); a special kind is obtained from the myrtle-leaved sumach or tanner's sumach (*Coriaria myrtifolia* L.)

Staghorn sumach (*Rhus typhina* L.), smooth sumach (*R. glabra* L.), and dwarf sumach (*R. copallina* L.) yield American sumach, which, however, is inferior to the European product, since it imparts to light leather a darker color.

The most valuable kind, designated common or Sicilian sumach, is obtained from *Rhus Coriaria;* the same plant also yields Spanish, Portuguese, and Greek sumach. WIESNER states that the better grades of the French product are prepared from the leaves of the same shrub. According to DU HAMEL, *Coriaria myrtifolia* yields Provençal sumach (from Montpellier), the leaves of which, mixed with oak bark, are used in tanning. Both Triest and Venetian sumach, also that from Hungary and South Tyrol, are derived from *Cotinus.*

Rhus Coriaria contains the largest amount of tannin. In Sicily, only the shoots are allowed to grow; these are cut near the ground with sickles in the first part of August, dried in the sun, and the leaves removed either by hand or by threshing. The leaves thus obtained are ground in special mills to a coarse powder which is separated into three grades: (1) fine sumach, 1st quality; (2) fine ribs and coarsely ground petioles; (3) coarse ribs and petioles. The last-named grade is rejected; the second grade, however, is reground and placed on the market as "fine sumach, 2d quality". A variety known as "Sommacco fimenedda" yields, according to ANDREASCH, a product with a smaller tannin content than the valuable species.

---

[1] F. ANDREASCH: Sicilian. Sumach und seine Verfälschungen. Ztsch. Angew. Chem. 1898, 1154. T. F. HANAUSEK: Realenzyklopädie d. ges. Pharm. 2. Aufl., **11**, 699. SEMLER: Tropische Agricultur., **2**, 538. With regard to the tannin content see A. LIDOW: Jour. Russ. Phys. Chem. Gesell. 1888, and Ber. Deutsch. Chem. Gesell. 1888, **21**, No. 18, 889.

Fine sumach is a gray-green powder of variable fineness, with a faint but peculiar odor and an astringent taste. The product, at least that found on the European market, always contains small, cylindrical, ochre-yellow or reddish-yellow fragments of the stem, the presence of which, so it appears, establishes the authenticity of the product, but at the same time lowers its value.[1]

1. **SICILIAN SUMACH.**—The simple odd-pinnate leaf of *Rhus Coriaria* has 5–8 pairs of leaflets (usually 5–6 pairs) and an odd terminal leaflet, which are either ovate to elongated-ovate, short-pointed, in some cases serrate, in others crenate[2] (Fig. 182, *a*), or broadly ovate to rounded-ovate, truncate with entire edges (Fig. 182, *b*). The upper side is sparingly pubescent; the under side, particularly along the nerves, is downy pubescent and glandular, as is also the petiole. Branching off from the prominent midrib are 7–12 straight or very slightly bowed veins, each of which sends off near the border a distinct branch; the vein itself ends in the point of one of the teeth, while the branch runs to the reentrant angle at the base. There is no formation of loops.

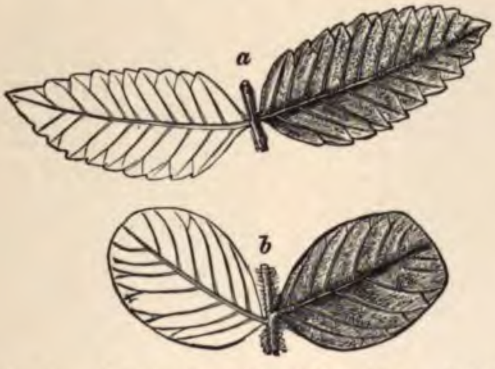


FIG. 182. Sicilian Sumach (*Rhus Coriaria*). Natural Size. (T. F. HANAUSEK.)
a toothed leaflets; *b* entire leaflets.

---

[1] Genuine sumach is not infrequently adulterated, chiefly with leaves of *Tamarix Africana*, *Pistacia lentiscus*, *Ailanthus glandulosa*, fig, grape vine, carob bean, and *Cistus salvifolius*. In Trento, South Tyrol, the leaves of bearberry (*Arctostaphylos Uva ursi* Spreng. = *A. officinalis*) are gathered.

[2] Hence the old designation "elm-leaved sumach". See PHILLIP MILLER: Dictionary of Gardening.

Since Sicilian and Venetian sumach can be distinguished by the structure of the two epidermal layers, only these layers are here described.

The Upper Epidermis (Fig. 183) is made up of polygonal, rather sharply angular cells which are covered by a finely but distinctly striated cuticle (*cu*). Here and there occur narrow stomata (*sp*) and short, unicellular, bristle-like hairs (*h*) with a strongly thickened base. Numerous oxalate rosettes, present in the mesophyl, are seen through the epidermal cells.

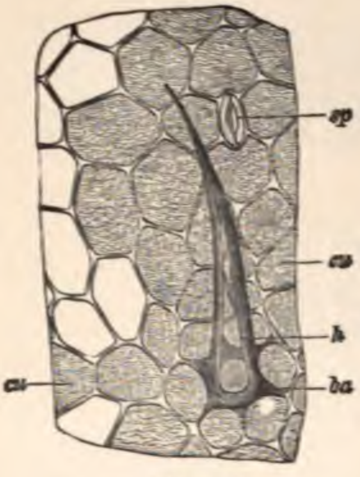


FIG. 183.

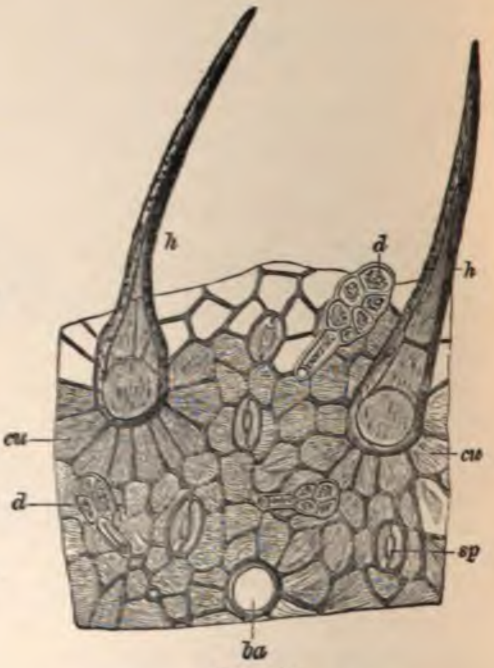


FIG. 184.

FIG. 183. Sicilian Sumac. Epidermis of Leaf in Surface View. (T. F. HANAUSEK.) *sp* stoma; *h* hair with thickened base; *cu* striated cuticle.

FIG. 184. Sicilian Sumac. Lower Epidermis of Leaf in Surface View. (T. F. HANAUSEK.) *sp* stoma; *h* bristle hairs; *ba* scar of hairs; *d* glandular hairs; *cu* striated cuticle.

Lower Epidermis (Fig. 184).—The cells are polygonal, like those of the upper epidermis, but are smaller, do not have such sharp angles, and often have curved walls. Beautiful cuticular striations (*cu*), formed by the folding of the cuticle, are distinctly evident. Distributed among these cells are numerous stomata, also bristle hairs and glandular hairs. The bristle hairs (*h*) are large, unicellular or bicellular, thick-walled, warty, and have a broad, strongly thickened base (*ba*) about which the epidermal cells form a rosette. The glandular hairs (*d*) are multicellular and consist of a long narrow cell forming the stem and several glandular cells united to form the head. The parenchyma cells seen through this layer are small.

Genuine sumach contains, in addition to tannin, a yellow coloring substance, known as **Myricetin,** which is identical with that formed in the bark of the Chinese plant *Myrica nagi* Thunb.[1]

2. VENETIAN SUMACH.—The leaf of *Cotinus Coggygria* Scop. is simple, much larger than the leaflets of true sumach, obovate, ovate, or rounded, entire, truncate, smooth throughout, and very long-petioled (Fig. 185). Branching out from the prominent midrib at broad angles are rather prominent veins which are lost toward the margin in a fine network.

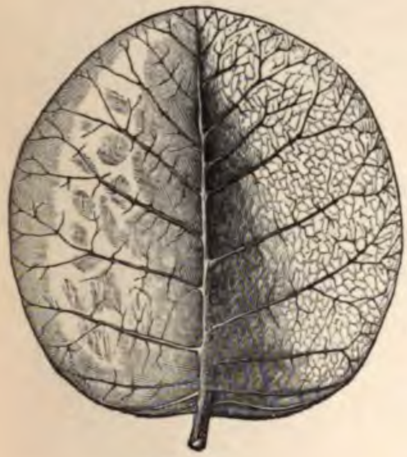


FIG. 185.

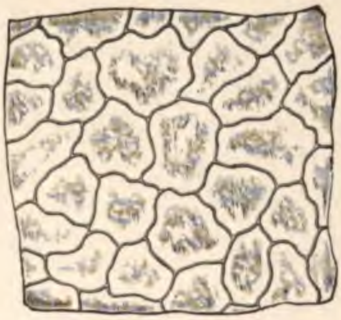


FIG. 186.

FIG. 185. Venetian Sumac (*Cotinus Coggygria*). Natural Size. (T. F. HANAUSEK.)

FIG. 186. Venetian Sumac. Upper Epidermis in Surface View. (T. F. HANAUSEK.)

Upper Epidermis (Fig. 186).—This consists of irregularly rounded cells with thin wavy walls. Hairs and stomata are wanting, and there is no evidence of cuticular striations.

Lower Epidermis.—The cells are smaller and more rounded than those of the upper epidermis. Numerous stomata are present.

---

[1] PERKINS and HUMMEL: Chem. News, 1896, **74**, No. 1919, 220.

3. **MYRTLE-LEAVED SUMACH.**—The leaves of *Coriaria myrtifolia* L.,[1] known as myrtle-leaved or tanner's sumach and on the Continent as *redoul*, were formerly used in medicine and for the adulteration of senna leaves, but at the present time are of importance as a tanning and dyeing material.[2] BÖHMER[3] stated in 1794 that the leaves mixed with green vitriol served to dye wool and silk violet colors, but that the product was of greater importance for producing durable blacks, also for accelerating the tanning process, although used alone it did not yield a sufficiently pliable leather. Of interest in this connection is the following quotation from BÖHMER's work: "The powdered leaves act much more energetically than oak bark. When the tanner in Provence and Languedoc is forced to sell his leather before he has had time to prepare it with evergreen oak (*Quercus Ilex*), he treats it with powdered redoul, which gives the leather sufficient firmness to be accepted by the purchaser." The leather by this treatment, as DU HAMEL[4] asserts, is more quickly finished, but is of inferior quality. The leaves are also extensively used for tanning sheep's and goats' skins.

Of late attention has been called to the value of the leaves for feeding the larvæ of the ailanthus silkworm (*Bombyx Cynthia*).[5] The leaves are decussate, simple, and of two quite different forms, namely the broad and the narrow, between which are numerous intermediate forms.

THE BROAD LEAVES (Fig. 187, *A*) are broadly ovate-lanceolate, the length and breadth in three examples being as follows:

	Length.	Breadth.
I	45 mm.	24 mm.
II	40 "	23 "
III	36 "	24 "
Average	40.3 "	23.6 "

From these results it appears that the average ratio of length to breadth is about 5:3.

---

[1] For an exhaustive account of the utilization of this product and numerous references see T. F. HANAUSEK: Redoul (Folia Coriariæ). Pharm. Post. 1892, **25**, 1333–1344. LEOPOLD VILLENEUVE (Étude sur le Redoul. Thèse. Montpellier 1893) describes the morphology of the flower and fruit, also the anatomy of the vegetative organs.

[2] Mentioned by PLINIUS as a tanning material (Naturg. Book 24, Chap. 54).

[3] Technische Geschichte der Pflanzen (1794), **2**, 224.

[4] Arbres, **1**, 130.

[5] BAILLON: Sur un nouvel usage du redoul. Bull. mens. Soc. Linn. Paris, 1880, 236–237. Other species of *Coriaria* are used in the arts. The ink plant (*Coriaria thymifolia* Humb.) of New Granada yields an indelible ink, and *Coriaria ruscifolia* L. a black dye.

THE NARROW LEAVES (Fig. 187, *B*), which appear to be the more numerous, are of an ovate-lanceolate or rounded rhomboidal-lanceolate type. Three examples had the following measurements:

	Length.	Breadth.
I	34 mm	15 mm
II	35 "	16 "
III	35 "	16 "
Average	34.6 "	15.3 "

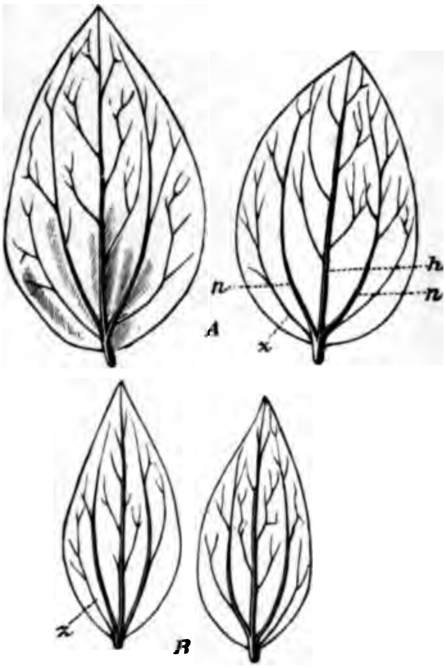


FIG. 187. Myrtle-leaved Sumac (*Coriaria myrtifolia*). Leaves, Natural Size. (T. F. HANAUSEK.)

A broad leaves; *B* narrow leaves. *h* midrib; *n* prominent side veins; *x* branch of vein grown to be independent.

The ratio of length to breadth is about 7:3. These dimensions apply to the majority of the leaves, especially those on the middle of a branch; the lower leaves are mostly much smaller and more rounded.

The leaves are sometimes slightly anisophyllous, always entire, smooth, glabrous, sessile or short-petioled, on the upper side dark green, on the lower side light green. The specific character of the leaf is the nature of the nervation. This may be described as radiating and curvilinear. The leaf appears to be three-ribbed, which I explain as follows: A straight midrib (Fig. 187, *h*) extends the length of the leaf to the slightly tapering apex. Two veins or secondary ribs (*A*, *n*), one on each side of the midrib, spring from the latter near the base and extend in gentle curves nearly to the end of the leaf. As far as the middle of the leaf, and also even beyond, these veins are quite strongly marked. The other nerves are exceedingly delicate, branch off at very narrow angles, and anastomose with one another at the ends. The lowest branch of each of the two main veins arises near the base of the leaf and may be regarded as an independent vein; therefore it may be said that there are 4–6 longitudinal veins or ribs.

The bifacial structure of the leaf is evident from Fig. 188. Beneath the upper epidermis (*ep*) are two layers—rarely only one layer—of **Palisade Parenchyma** (*p*), the cells of the inner layer being either the same height as those of the outer layer or else shorter. Calcium oxalate occurs in the cells of this inner layer either as simple crystals or round concretions (*k*) with the appearance of being corroded.

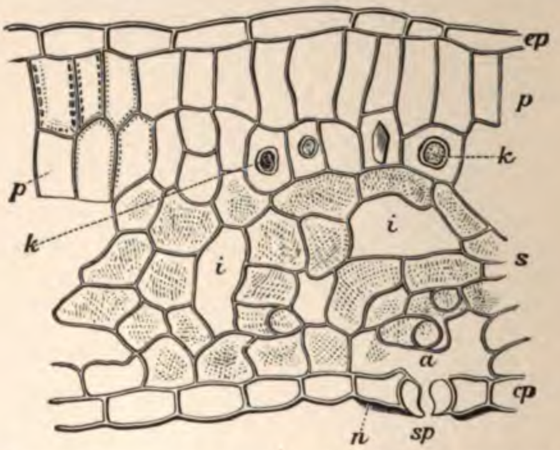


FIG. 188. Myrtle-leaved Sumac. Cross-section of Leaf in Potash and Glycerine. ×350. (T. F. HANAUSEK.)

ep upper and lower epidermis; *p* first and second palisade layers; *s* spongy parenchyma; *i* intercellular spaces; *sp* stoma; *n* accompanying cells; *a* respiratory cavity; *k* oxalate crystals.

The **Spongy Parenchyma** (Fig. 188, *s*) is of the usual type with intercellular spaces (*i*) of various sizes. The cells have 3–4 outgrowths and, like the palisade cells, contain very small spindle-shaped or almost rod-shaped chlorophyl grains which are especially distinct after treatment of the section with alcohol and dilute hydrochloric acid.

A cross-section through the midrib of the leaf shows a **Vascular Bundle** embedded in a collenchymatous ground tissue. The lignified elements of the bundle take on a red color and become very distinct on treatment with phloroglucin and hydrochloric acid. A single layer of cells lignified on the inner side forms the sheath, within which are 3–4 groups of vessels each containing 5–10 spiral vessels separated by rows of cells resembling medullary rays. Toward the base the vessels show a converging arrangement. In the main veins there are 2–3 groups of vessels, in the fine veinlets only one.

The Upper Epidermis (Fig. 189) is composed of sharply polygonal cells which in cross-section (Fig. 188, *ep*) are flattened rectangular, 32–48μ long. The rather thin walls show numerous pits and the outer surface, owing to the cuticular membrane, is somewhat granular or, less often, striate (Fig. 189, *cu*). Stomata (*sp*), although not rare, are not so numerous as on the lower epidermis. Each stoma is flanked by two accompanying cells (*n*) on which cuticular striations are usually evident.

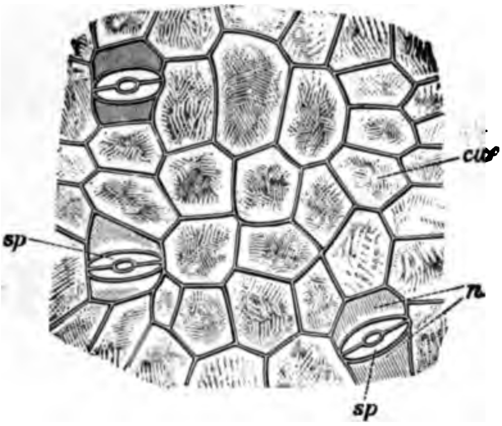


FIG. 189. Myrtle-leaved Sumac. Surface View of Upper Epidermis of Leaf in Water. ×350. (T. F. HANAUSEK.)
sp stomata; *n* accompanying cells; *cu* granular-striated cuticle.

The Lower Epidermis (Fig. 190) differs somewhat from the upper and is the most valuable tissue in the diagnosis of the powder. The cells in surface view are irregularly polygonal, mostly with curved, strongly pitted walls (*po*), and owing to the cuticle are more conspicuously striate than those of the upper epidermis. Adjoining each of the numerous stomata are two accompanying cells (*n*) the very distinct, parallel, cuticular striations of which present a striking appearance. These folds of the cuticle are also visible in cross-section (Fig. 188, *ep*, *n*), resembling a fine-tooth comb. The respiratory cavities (*a*) are very large. The total length of accompanying cells with stomata is 50–60μ, of the other epidermal cells 43–60μ.

We have selected this leaf for a somewhat exhaustive treatment for the reason that it gives us an opportunity to demonstrate the presence of certain cell contents in a microchemical way. The high tannin content (16–24.37 per cent) is shown by the reaction with iron salts. According to R. BÖTTGER,[1] the leaf should first be boiled for a few minutes with water before adding the reagent. Ferric chloride colors the contents of all the cells blue-black; only the lower epidermis appears to contain a small amount of tannin.

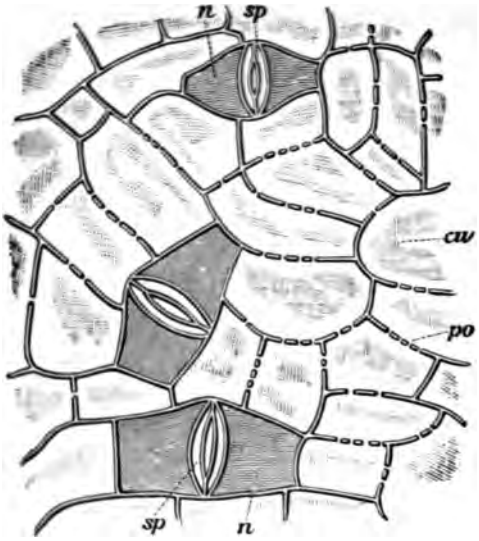


FIG. 190. Myrtle-leaved Sumac. Surface View of Lower Epidermis of Leaf in Water. ×350. (T. F. HANAUSEK.)

po pores of cell membrane; *sp* stomata; *n* accompanying cells; *cu* granular-striated cuticle.

Treatment with dilute sulphuric acid causes the separation of numerous crystals of calcium sulphate formed from the **Calcium Oxalate**.

Potash, especially after treatment with alcohol, colors the mesophyl brown red, and forms in the liquid a brown precipitate. On addition of sulphuric acid the tissues are changed again to bright green. The same reactions are also obtained after boiling the section in water and washing until it gives only a faint reaction for tannin. This reaction with potash is very probably due to the poisonous glucoside **Coriamyrtin,**[1] as this is decomposed by solutions of alkalies with the formation of brown products. Ammonia also forms a brown precipitate in the mesophyl.

---

[1] Arch. Pharm. 1874, 505.

The characteristic microchemical reaction for coriamyrtin is obtained by the hydriodic acid-soda test. A fragment or section of the leaf is first laid in an old solution of iodine in potassium iodide, which, as is well known, always contains a certain amount of hydriodic acid. In a short time the object appears almost black owing to the formation of a black precipitate in the cells. The iodine is then removed by means of a filter-paper and the object placed in strong alcohol. By this treatment the object is cleared, owing to the solution of the precipitate, and the green color again predominates. If a drop of concentrated soda solution is now added, a purple-violet color immediately appears and deep-red granules separate from the object. In a section the formation of the purple color may be followed from the edge inward. After 10–15 minutes, or sooner if water is added, the striking color vanishes entirely and there remains behind a yellow precipitate. By this test it can be shown that coriamyrtin is present in all parts of the mesophyl; only the vascular bundles and the ground tissue about them do not contain it.

MISCELLANEOUS LEAVES.

Many leaves such as peppermint, curled mint, rosemary, patchouli, balm, etc., characterized by their content of essential oils, are used for the manufacture of these oils.

Two leaves, namely tobacco and tea, are among the most valuable alkaloidal products and are of great commercial importance. Numerous plants yield leaves used as drugs.

Among the herbs used in the arts are dyers' weed, weld, or wold (*Reseda luteola*), dyers' woad or pastel (*Isatis tinctoria*), and the species of *Indigofera.*[2]

---

[1] Realenzyklopädie d. ges. Pharm. 2. Aufl. 1905, **4**, 133.

[2] See H. Molisch: Wiesner's Die Rohstoffe des Pflanzenreiches. 2. Aufl. 1900, **1**, 423.

CHAPTER VI.

FLOWERS AND PARTS OF FLOWERS.

Among the limited number of flowers and parts of flowers of technical importance are saffron and safflower, used for dyes; cloves, orange flowers, etc., used for the manufacture of essential oils; and insect powder, *Pyrethrum*, a valuable insecticide. Cloves and saffron[1] are also valuable as spices and are described in works on the microscopy of foods. *Pyrethrum*, as found on the market, is usually in the form of a powder and is a subject for microscopic examination.

INSECT POWDER.[2]

Insect powder, or pyrethrum, consists of the medium or finely ground flower heads of several species of the genus *Chrysanthemum* (subgenus *Pyrethrum*).[3] Common Dalmatian insect powder is obtained from *C. cinerariæfolium* (Trev.) Bocc., Persian insect powder from *C. roseum* Web. et Mohr (= *Pyrethrum carneum* M. B.) and *C. Marschallii* Aschers. (= *P. roseum* M. B.).

The whole flower heads of the different species show marked distinctions, but it is a difficult matter to determine the source of the powder. It is said that those in the trade distinguish the two principal kinds by the odor; the color gives but little information. Pure insect powder[4] is always gray-yellow; the bright-yellow color so highly esteemed by the purchaser is due usually to a dyestuff such as chrome-yellow, curcuma, etc.

---

[1] See also M. Kronfeld u. T. F. Hanausek: Geschichte des Safrans und seiner Cultur in Europa. Die Safranfälschungen. Ztschr. Nahr. Unters. Hyg. Warenk. 1893.

[2] Collin: A study of the Anatomy of Insect-flowers. Pharm. Jour. London, IV, 1901, **13**, 474–476, 503–506. T. F. Hanausek: Beiträge zur mikroskopischen Characteristik der Flores Chrysanthemi. Pharm. Post. 1892, **25**, Nos. 1, 6, 27, and 30. Linsbauer: Wiesner's Rohstoffe des Pflanzenreiches. 2. Aufl. 1900, **2**, 671. S. Malfatti: Ueber kaukasiches Insectenpulver. Pharm. Post. 1893, **26**, 165, 181, 193, 205. Moeller: Pharmakogn. Atlas, Table 10. Tschirch u. Oesterle: Anatomischer Atlas, Table 40, p. 171. Unger: Phar Ztg 1887, No. 96, and 1888, Nos. 11, 18 and 23. Vogl: Arzneikörper, 116.

[3] Engler u. Prantl: Pflanzenfamilien. IV. Theil, **5**, 277–278.

[4] T. F. Hanausek: Realenzyklopädie d. ges. Pharm. 2. Aufl. 1906, **7**, 49.

The flower heads of the Oriental species of *Chrysanthemum* are distinguished chiefly by the form of the involucral scales and the length of the ovary. The involucre of *C. Marschallii* is flattened top-shaped and, according to A. VOGL,[1] has elongated ovate to lanceolate blunt green scales which on the end and edges are dark red to black-brown and scarious. "The corolla of each of the 30 (according to UNGER 26) female ray flowers broadens into a rose-red or white, somewhat plicate unequally blunt three-toothed and seven-nerved[2] tongue up to 15 mm. or more in length." The corolla of the disc flowers is yellow, five-toothed, scarcely longer than the brownish, ten-striate ovary. The latter has a membranous pappus.

The flowers of *C. roseum* have pointed or blunt, mostly green involucral scales with dark-brown membranous margins and a ten-ribbed ovary 1 mm. long. The corolla of the tubular flowers is much longer than the ovary.

Chrysanthemum cinerariæfolium, a native of Dalmatia and Herzegovina, where it is also cultivated, yields what is at present the most important and most efficient insect powder. The involucre of the Dalmatian flowers is nearly hemispherical and consists of short outer and long inner scales. The outer scales of the involucre, which are characterized by their blunt lanceolate form and pronounced keel, are rough and of a brownish color on the outer, lustrous and of a straw-yellow color on the inner, surface. The inner scales are spatulate, much longer than the outer, and have a narrow dry membranous white border which is much broader on the outer end. No keel is present.

In this species also we find both ray and disc flowers. The ray flowers (Fig. 191) are ligulate, with a short tube from which protude the two limbs of the stigma (*N*). The ray (*Z*) is mostly three-toothed, the middle tooth being often much smaller than the other two. Four principal veins (h^1–h^4) proceed from the base of the ray nearly to the toothed apex, where each splits into two curved branches which connect adjoining nerves in a series of pointed arches. The secondary nerves (*nn*) run parallel to the main nerves, but are more slender, those adjoining the outer branches of the main nerves uniting with them to form pointed arches. Sometimes there appear to be five main ribs, but in all the flowers which I have examined the fifth was found to be a strongly developed outer vein of one of the outer main ribs.

---

[1] *Loc. cit.*

[2] UNGER states that each petal has 15 vascular bundles.

The disc flowers have a tubular five-lobed corolla which is 1.5 mm. long and is borne on the ovary. The whole flower is 6 mm. long. Before we describe the microscopic characters of this product we will consider some of the properties and reactions of the cell contents.

On treatment of the powder with a strong potash solution an intensely yellow solution is obtained which, on addition of acetic acid, is decolorized in a short time. Nearly all the parts of the flower, even the colorless pappus or calyx, give this reaction with alkali, although doubtless the ovary is the chief source of the coloring substance. If the ovary is isolated and placed in potash, a deep-yellow color is obtained. Concentrated sulphuric acid gives a yellow-green color before carbonization sets in, nitric acid a yellow-brown color. Hydrochloric acid acts much like sulphuric acid. Ferric chloride gives a strong greenish-black tannin

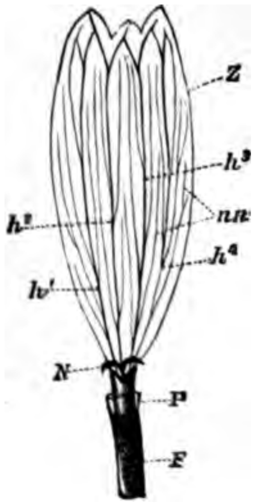


FIG. 191.

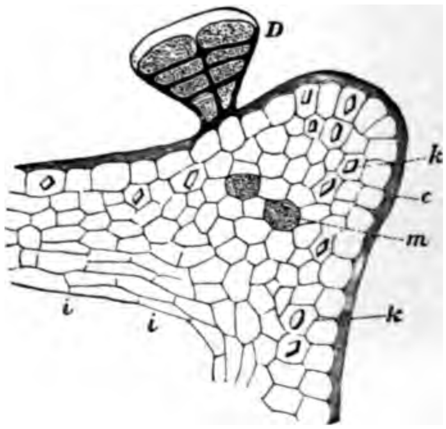


FIG. 192.

FIG. 191. Insect Powder (*Chrysanthemum cinerariæfolium*). Ligulate Flower under Lens. (T. F. HANAUSEK.)

F ovary; *P* pappus; *N* stigma protruding from short tube of corolla; *Z* ray; h^1 to h^4 principal veins; *nn* secondary veins.

FIG. 192. Insect Powder. Part of Cross-section of Ovary of Disc Flower. (T. F. HANAUSEK.)

D club-shaped glandular hair; *c* outer membrane; *m* secretion tubes; *k* oxalate crystals; *ii* inner epidermis lining the cavity.

reaction. On soaking a flower head in about 150 cc. of pure water a distinct yellow solution is obtained.

The insecticidal principle, according to several authors,[1] is an essential oil with an acid reaction named by SCHLAGDENHAUFFEN and REEB **Pyrethrotoxic Acid**. In addition, an alkaloid (**Chrysanthemin**) and a phloroglucidal substance (**Pyrethrosin**) have been isolated.

In order to identify the fragments of tissues found in insect powder, a methodical investigation must be made of the flower heads. These consist of the following organs and parts of organs: (1) Pistils of the disc and ray flowers (*Gynœceum*); (2) Stamens (*Andrœcium*); (3) Calyx (*Pappus*) of the disc flowers; (4) Corolla of the ray flowers; (5) Corolla of the disc flowers; (6) Involucre; (7) Receptacle; (8) Peduncle (Stem of the flower).

1. **PISTIL.**—The ovary of the disc flowers is roundish in cross-section and has five pronounced ribs. An epidermis with strikingly thick colorless outer membrane (Fig. 192, *c*) covers a tissue of delicate cells with very numerous crystals of calcium oxalate. The outer membrane consists in large part of cellulose, since it is colored blue by iodine and sulphuric acid. Almost every cell of the parenchyma contains a large monoclinic, rhombohedron-like or prismatic-tabular single crystal (*k*) and in surface view the tissue appears as if strewn with these crystals. The epidermis bears peculiar club-shaped oil glands (*D*), which occur only between ribs. These club-shaped glands are very characteristic of the *Compositæ*. They consist of two rows of cells, four in each row, which are small at the base but increase in size toward the end. Seen from above, the cells are strikingly elliptical in form. The cuticle over the upper pair of cells is separated from the cells themselves, forming a cavity in which is contained the secretion, the subcuticular secretion of TSCHIRCH.[2] In the tissues of the ribs, as well as in the tissues between them, occur secretion tubes (*m*) containing brown solid (i.e., dried) lumps which break into angular pieces. This substance swells in water, still more in potash, to a worm-like mass striated on the surface and finely granular within. On addition of alcohol and warming, they largely dissolve, although by cold alcohol they are little affected. The secretion also swells in ammonia, but only a small part of it dissolves, forming a

---

[1] See especially THOMS: *Croton flavens* L. und *Chrysanthemum cinerariæfolium*. Ber. Deutsch. Pharm. Gesell. 1891, **1**, 241–247.

[2] Angewandte Pflanzenanatomie, 467.

light-yellow solution. The characteristic saffron-yellow color obtained with potash is due in part to the solution of this balsam. On treatment with boiling potash, there remains undissolved a considerable residue in the form of dark-brown drops containing very small granules. If the tissue is thoroughly washed in water, after treatment with potash and alcohol, there still remain undissolved isolated brown masses which are not decolorized by acetic acid.

The secretion tubes extend in the form of thick brown strands through the entire length of the ovary, some of them ending blindly near the insertion of the pappus, others extending through the style and ending in the broad lobes of the stigma. In the latter case they diminish gradually in size in their course through the style. At the base of the ovary is formed a circle of beautiful polyhedral, strongly sclerenchymatized cells which serve as a dividing layer through which the fruit is separated from the receptacle. Delicate spiral vessels occur in the vascular bundles of the pistil.

The tissue of the style of the ray flowers is a parenchyma with somewhat thick-walled, in parts porous, but not sclerenchymatized cells, some of which are filled with deep-brown contents. The presence of slender secretion tubes has already been noted. On the style and also on the lobes of the stigma are bunches of long colorless papillæ, often with adhering pollen grains.

Of all the organs the pistil is most abundantly provided with glands. This part is also characterized by the occurrence of calcium oxalate only as single crystals.

2. **STAMENS.**—Pieces of considerable size not infrequently occur in the powder (Fig. 193). A free lobe of the anther tube (connective) is of somewhat regular triangular form and consists of elongated parenchyma cells (*m*). The epidermis is strongly cuticularized (*c*). According to Tschirch and Oesterle,[1] the connective on the borders consists of sclerenchymatized cells. The inner layers of the anther tube consist of cells with characteristic thickenings. Where the thickenings occur on the longitudinal walls they appear in the form of projections which give the walls a comb-like appearance; the thickenings themselves are not visible in the mount.

The pollen grains are 27–29μ in diameter, round, with three pores, numerous warts and prickles.[1] In potash they swell to 34μ, become transparent, and show distinctly the **Exine**, or outer wall, and the **Intine**, or inner wall. The former bears the prickly excrescences; beneath it lies a finely striate rod layer. The pollen grains are unicellular.

---

[1] Anatomischer Atlas, 172.

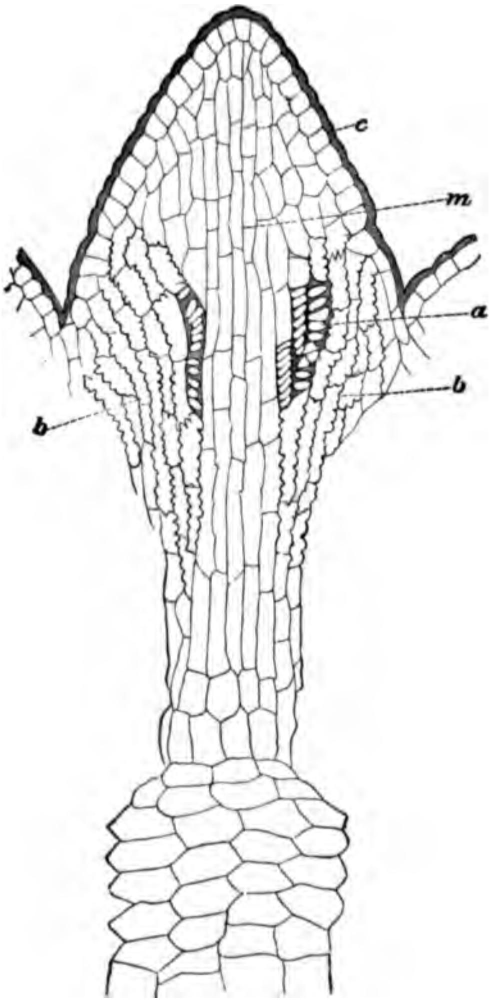


FIG. 193. Insect Powder. Part of Anther Tube Showing a Lobe (Continuation of Connective). (T. F. HANAUSEK.)

m longitudinally elongated cells; *a* reticulated thickened cells; *b* same as last, showing only the small projections forming the place of attachment of the thickened bands; *c* cuticle.

---

[1] "The unicellular pollen grains have a coarsely prickly exine and a rod layer which gives the surface a granular appearance." TSCHIRCH u. OESTERLE: Anatomischer Atlas, 172.

3. The **CALYX,** or **PAPPUS** (Fig. 191, *P*), forms a short, thin, dry, colorless, transparent tube, the diameter of which is greater than that of the corolla tube. The border is irregularly and gently wavy. Potash imparts a bright yellow to the colorless membrane, which is visible to the naked eye. On the outer side of the pappus the epidermal tissue is of longitudinally elongated, sharply defined cells with colorless walls and distinct middle lamella; on the inner side the cells are much shorter and their longitudinal walls are seldom parallel. The mesophyl, especially in the basal part, contains numerous longitudinally elongated, porous sclerenchyma cells. Spirally thickened cells occur in the edges and serve to stiffen the tissues (Fig. 194, *sp*). The pappus also contains single crystals but no tubes.

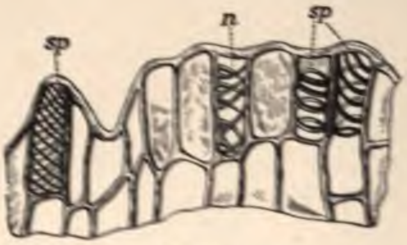


FIG. 194.

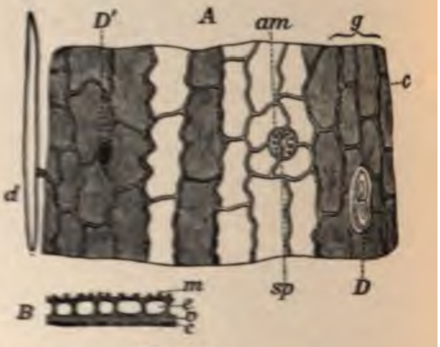


FIG. 195.

FIG. 194. Insect Powder. Part of Edge of Pappus. (T. F. HANAUSEK.)
n and *sp* spirally thickened border cells.

FIG. 195. Insect Powder. Outer Epidermis of Ligulate Flower. (T. F. HANAUSEK.) *A* surface view: *g* cells overlying a bundle of spiral vessels; *sp* stoma with *am* starch grains; *D* club-shaped gland from above; *D'* basal cells of last after removal of outer cells; *d* T-hair.—*B* cross-section: *c* cuticle; *v* cellulose lamella; *r* lumen; *m* beginning of inner tissues.

4. **COROLLA OF THE RAY FLOWERS.**—The ligulate flowers are colored yellow by potash, also after standing several days in water. If the colorless epidermis removed from the inner side is treated with potash this also assumes a yellow color, showing that the coloring substance is present also in this tissue.

The two epidermal layers of the ray are of entirely different structure.

The **Outer Epidermis** is like the epidermis of an angiospermous leaf in structure (Fig. 195). It consists of longitudinally elongated cells with wavy walls and distinct cuticular striations; only where these cells occur over a vascular bundle (*g*) are they shorter and have straight walls. Only a few stomata (*sp*) are found on the part of the epidermis lying nearest the tube; they are much more numerous near the toothed end. The stomata are circular or broadly elliptical and are surrounded by 4–5 accompanying cells. The guard cells contain globular starch grains (*am*). The outer epidermis always bears club-shaped glands (*D*) of the same kind as are found on the pistil. Although not so abundant as on the latter organ, they are always present in considerable numbers. In addition to glands there are present T-shaped hairs or cross-cell trichomes (*d*) which consist of a very short basal cell and a very long end cell, pointed at both ends, at right angles to the last. These hairs are also found on the corolla of the disc flowers and frequently occur in other plants of the *Compositæ*.

The **Inner Epidermis** consists of polyhedral cells with strongly projecting, almost semi-ellipsoidal or hemispherical outer walls (Fig. 196, *A*). These papillæ are seen to advantage only on the fresh flowers; if the material is dry, it is necessary to soak it with dilute alkali. If the dry petals are mounted in cold water, most of the papillæ are shrunken and collapsed so as to present the appearance shown in Fig. 196, *B*. It should be noted that the cut shows, as it were, the appearance as seen in two different focal planes. With the higher focus we see only the wrinkled calottes in the form of indistinct, irregular triangles or pointed ovals (Fig. 196, *B*, *c*), with the lower focus, the polygonal cell outlines (*p*), on which are often small folds and knotty emergences. The papillæ have very distinct cuticular striations which converge toward the highest point.

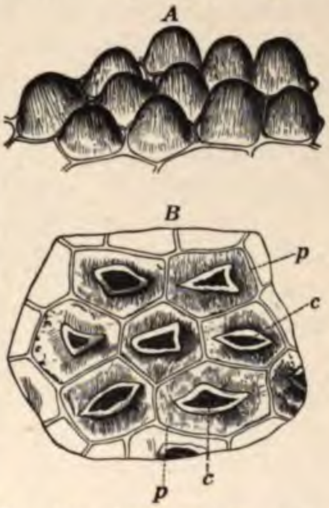


FIG. 196. Insect Powder. Inner Epidermis of Ligulate Flower. (T. F. HANAUSEK.)

A cells with normal papillæ.—*B* with shrivelled papillæ: *p* polygonal basal part; *c* shrunken calottes.

Mesophyl.—The cells between the epidermal layers are colorless, rather narrow, of various lengths, and have pointed or irregular branch-like offsets at right angles to the walls separating adjoining cells. In this manner a loose spongy parenchyma is formed with numerous intercellular spaces communicating one with another, thus permitting a ready circulation of air and at the same time giving the ray, which contains scarcely any mechanical elements, a low specific gravity. The veins contain spiral vessels and longitudinally elongated, porous, lignified sclerenchyma elements. With the exception of the cuticle, the club-shaped glands, and the bundle elements, all the cell walls give the cellulose reaction. On treatment of cross-sections with iodine and sulphuric acid, the distinction between the yellow cuticle and the blue cellulose walls is particularly striking (Fig. 196, *B*).

5. **COROLLA OF THE DISC FLOWERS.**—The **Outer Epidermis** bears numerous club-shaped glands and occasional T-hairs. The epidermal cells are mostly longitudinally elongated and have a thick outer wall and a transversely or longitudinally folded cuticle.

The **Inner Epidermis** has a similar structure. If the corolla is cut on one side from base to apex, spread out on a slide inner side up, held up to the light, and examined with a lens, there will be seen under the point of each of the five teeth a peculiar thickened place which extends like a hood from the point downward and ends as one of the side walls of a cavity. The microscopic structure of this formation is as follows: The border cells at the end of the tooth are arranged in a row; they are longitudinally elongated, all being bent toward the point, relatively thick-walled and closely united without gaps. The cells of the neighboring rows gradually decrease in length until they are round and then become elongated, forming papillæ which extend in the direction of the longitudinal axis of the tooth forming a wall. The side of the wall—consequently the back of the cavity above mentioned—consists of uniform roundish thick-walled cells. All the cells contain plasmic contents and crystals.

In the transition region, below the five-toothed edge of the corolla, the cells of the inner epidermis again become axially elongated and their walls become much thinner. In each cell a crystal rosette is evident. At the base of the corolla the cells are again shorter and overlie a somewhat regular parenchyma.

Especially noteworthy are the crystal formations. Very seldom are simple crystals present; many crystals which appear to be simple show along the surface of the prism a part which refracts the light in another direction and is undoubtedly a twinning plane. The twin forms have for the most part a constriction in the middle and on the narrow end a corresponding angle. Often the clusters show a series of developmental forms. In its simplest form the cluster consists of a large central whetstone-like crystal penetrated by several radially arranged needle-shaped crystals. A modification of the last consists of a short prismatic crystal on one end of which is a bundle of radiating crystal needles. Sheaflike bundles of crystals constricted in the middle are numerous. The crystal rosettes are the forms with largest number of crystals.

We thus see that the corolla of *Chrysanthemum* would be an excellent material for demonstrating forms of crystals were it not for their small size; the largest clusters measure scarcely 10μ.

6. The **INVOLUCRE**, as already noted, consists of short outer and long inner scales.

OUTER SCALES.—The **Outer Epidermis** (Fig. 197) is made up of (1) relatively small, irregularly polygonal or gently wavy cells (*o*); (2) very numerous broadly elliptical stomata (*sp*), mostly surrounded by 3–4 accompanying cells; (3) numerous cross-cell trichomes or T-hairs (*h*); and (4) numerous club-shaped glands (*D*). The epidermal cells are covered by a coarsely striated cuticle, the wavy folds of which radiate from the outer borders of the stomata, while the stomata themselves are nearly smooth, i.e., appear to be free from striations. The explanation of this difference in the cuticle is found in the cross-section (Fig. 198). In a section through the keel we see an epidermis of cells with very thick laminated walls (*o*), which are especially strongly developed on the outer

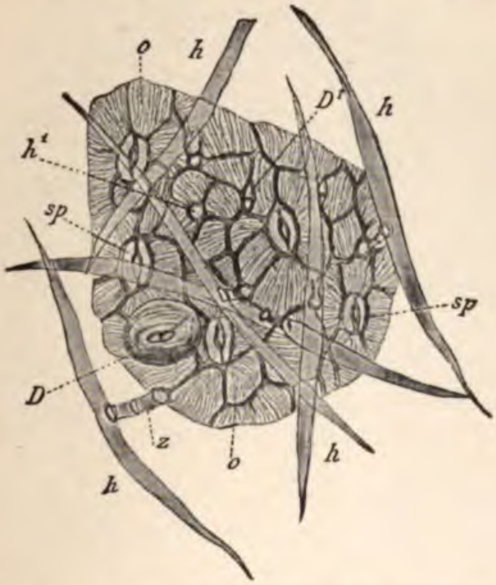
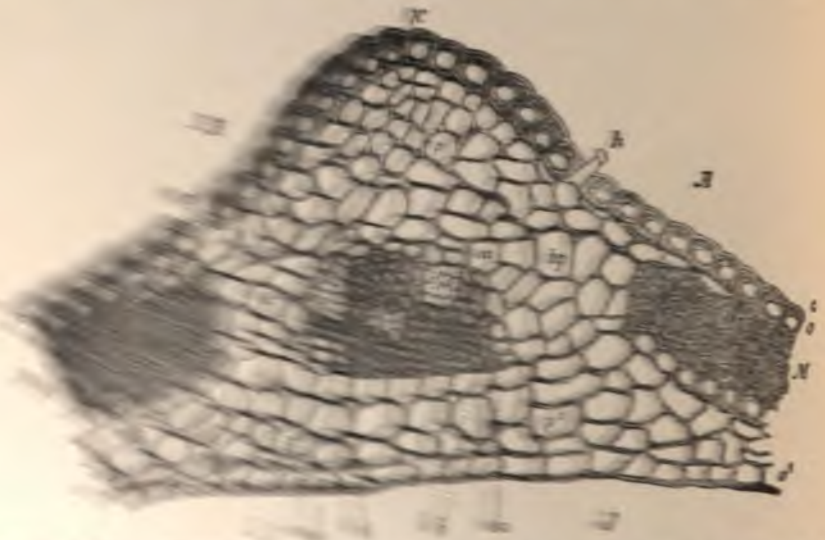


FIG. 197. Insect Powder. Outer Scale of Involucre in Surface View. (T. F. HANAUSEK.)
o outer epidermis; *sp* stomata; *h* T-hairs; *h'* scar of T-hair; *D* club-shaped glandular hair; *D'* pair of foot cells of last.

[illegible] The cuticular folds form a finely toothed border. Since the surface of the stomata (*sp*) is lower than that of the epidermal cells, and the [illegible] have a smooth cuticular coat, it is evident that only the epidermal [illegible] striations, while the guard cells are smooth.

The **Inner Epidermis** is much more simple in structure. In cross-section the cells (Fig. 198, *o'*) are irregularly quadrangular, often with



[illegible] through Keel. [illegible]

[illegible] inner epidermis; *p* [illegible] parenchyma; [illegible] sclerenchyma cells; [illegible]

[illegible] they are axially [illegible] and more or less [illegible] absent. Both [illegible] rounded paren- [illegible] intercellular spaces [illegible] which may be [illegible]

[illegible] cross-section after [illegible] After treatment [illegible] of [illegible] extending [illegible] ground tissue of the keel (Fig. 198, *p*), loose subepidermal parenchyma (*p'*), and, of course, the two epidermal layers. The lignified zone consists of three parts: (1) in the middle, the vascular bundle corresponding to the keel of the scale; (2) flanking the bundle on both sides, lignified parenchyma or sclerenchyma tissues (Figs. 198 and 200, *hp*, *sc*); (3) outside of the last on both sides, large plates of bast fibers and sclerenchyma cells (Fig. 198, *M*); these plates immediately adjoin the outer epidermis, entirely replacing the parenchyma and diminish in diameter toward the edge of the bract. The phloem of the vascular bundles is divided by intercalated mechanical tissues into three parts (Fig. 198, *ca*); the xylem contains very narrow spiral vessels and tracheids. On the periphery are bast fibers intermixed with richly pitted, somewhat elongated, knotty, often very bulky sclerenchyma cells and roundish, lignified, pitted parenchyma cells (Figs. 198 and 200, *hp*, *sc*). According to TSCHIRCH and OESTERLE,[1] two latex tubes also are present in the bundle.

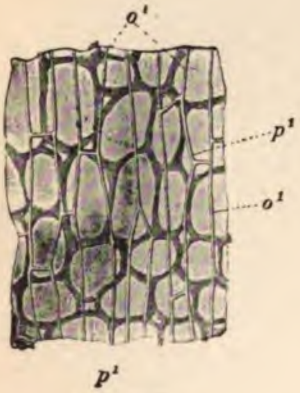


FIG. 199.

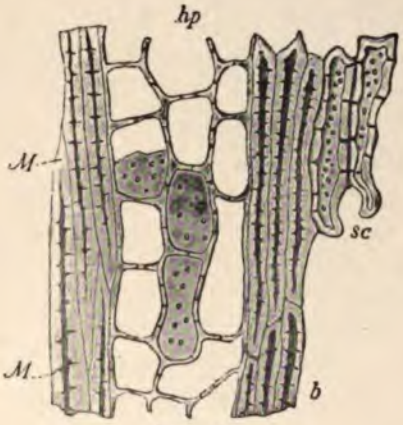


FIG. 200.

FIG. 199. Insect Powder. Outer Scale of Involucre. (T. F. HANAUSEK.) Longitudinal view of *o'* inner epidermis and *p'* underlying parenchyma.

FIG. 200. Insect Powder. Outer Scale of Involucre. (T. F. HANAUSEK.) Longitudinal view of *M* part of the bast-fiber plate; *hp* lignified parenchyma; *b* elements resembling bast fibers; *sc* sclerenchyma cells.

The INNER SCALES have no keel; on the margin they are beset with numerous T- and whip-shaped hairs. The colorless membranous margin is made up of longitudinally elongated, empty, thin-walled cells, which on the very border have rounded and, to a certain degree, isolated ends resembling hairs. The transition from the membranous margin to the thick colored part of the leaf is well marked in the epidermal layers.

---

[1] Anatomischer Atlas, Table 40, Fig. 16, *scb*.

Outer Epidermis.—The cells show very delicate cuticular wrinkles. On the membranous margin the wrinkles are so delicate that they are evident only after the most careful focusing of the objective. For this reason it is recommended to strip off the epidermis in water, thus securing very distinct surface preparations. In such preparations it may be seen that the longitudinally elongated cells on the upper part of the scale pass, in the middle and lower part, into nearly isodiametric forms with exceedingly delicate outline. The stomata are relatively large, very numerous, and on a level with the epidermal cells. The radial walls of the cells of this outer epidermis are much thinner than the tangential walls.

The **Inner Epidermis** consists of thin-walled cells which usually contain a yellow substance soluble in potash to a gamboge-yellow color. Through the extraordinarily thin and transparent cells of the epidermis may be seen the underlying sclerenchyma composed of axially elongated, pitted, strongly lignified elements which, on casual examination, might be taken for the relatively inconspicuous epidermal layer.

The **Mesophyl** of the inner bracts is similar in structure to that of the outer, but the mechanical plates consist of only a few layers of sclerenchyma fibers and the inner colorless tissue, with a capacity for swelling, is reduced to two layers of small thin-walled cells.

7. The **RECEPTACLE** forming the organic end of the axis consists essentially of a superficial, firm, and hard tissue of roundish, somewhat small, yellow-brown cells with small intercellular spaces and an inner pith-like parenchyma. The superficial tissue is raised on the surface so as to form small warts with an indentation at the end in which is inserted the flower. Small vascular bundles end in these depressions.

The inner pith tissue, in the central portion, is often torn or even wanting. It consists of large, roundish, colorless, and empty cells, the walls of which, in parts adjoining neighboring cells, are richly pitted, while in parts adjoining the numerous large intercellular spaces they are non-porous. Naturally the non-porous walls are the thinner. Notwithstanding their size and delicate structure the non-lignified pith cells do not suffer considerably on grinding and they may be found in large numbers in the powder.

8. The **PEDUNCLE** is hollow, has twelve ribs filled in with collenchymatous tissue, and as many vascular bundles and secretion tubes.

Of the tissues described, the elements of the involucre and ovary, fragments of the corolla, and numerous pollen grains are found in the greatest abundance in the powder.

Malfatti's description of Caucasian insect powder flowers corresponds very closely with the foregoing description, showing that the distinction between the two products must be slight. The ovary of the Caucasian species has nine to ten ribs. Only crystal rosettes of calcium oxalate are present; single crystals are absent.

Among the adulterants[1] of insect powder are mentioned the heads of other composite plants, especially *Chrysanthemum Leucanthemum* L. (ox-eye daisy) and *Helichrysum arenarium* DC. (*Flores Stœchadis citrinœ*, yellow cat's paw, hour-glass weed, yellow-moth weed). Recently the plant of Dalmatian insect powder has also come into the market. This is probably ground with the flowers. Insect powder mixed with quassia is known as " ori ".[2]

---

[1] See H. W. SNOW: On the Detection of Adulteration in Insect Powder. Stearn's A New Idea, 1895, Sept., Oct.

[2] Riedel's Mentor, 1904, 131.

CHAPTER VII.

FRUITS AND SEEDS.

LIKE fiber materials and wood, fruits and seeds are among the most important raw materials of the vegetable kingdom, since they are employed in enormous quantities as foods for man and cattle, as well as for the manufacture of industrial products such as fatty and essential oils, starch, tanning, and dyeing materials.

Numerous problems with reference to this class of products are submitted to the technical microscopist for solution; he must determine the origin of whole fruits and seeds and the composition of powdered materials made from them, detect admixtures and adulterants, and decide as to the value or worthlessness of such products. This work requires an accurate knowledge of the macroscopic appearance and structure of the fruits and seeds, as well as of the microscopic characters of the tissues and cell contents. Since fruits and seeds are the most important store-houses of reserve material, the nature of the cell contents is of no little importance. Before taking up the microscopic investigation of these products, we will acquaint ourselves with the most important facts with regard to their morphology and classify them according to their microscopic characters.

I. Kinds of Fruits. Morphology.

The **Gynæceum** of the flower consists of one, or several, or many pistils, each made up of one or several leaves. In a typical leaf there are three parts: (1) the **Sheath**; (2) the **Petiole**, or leaf stalk; (3) the **Blade**, or lamina. Of the three parts of the pistil, the **Ovary** corresponds with the leaf sheath (or sheaths, if the pistil is made up of several leaves), the **Style**, with the petiole, and the **Stigma**, with the leaf blade. Usually the stigmas are very small. In species of *Iris* and *Crocus*, however, they are flattened or thread-shaped, thus showing more clearly their relation to the leaf blade. If the pistil after fertilization ripens until it reaches its full maturity, it becomes a **Fruit**. A fruit is then a completely developed and ripened pistil. Examples of fruits, according to this definition, are the palm-nut, the poppy capsule, the pods of the legumes, etc.

In many cases, however, this definition does not suffice, since the sepals or the peduncle may also take part to a greater or less extent in the development of the fruit. The apple is a well-known example of a fruit developed from pistil and receptacle. The pistil of the flowers of the apple and other pomes is contained in a jug-shaped cavity of the receptacle and is united with the walls of this cavity so that both develop into the fruit. Still more striking examples of fruits developed from both pistil and receptacle are the fruit of the rose, the hollow, globular, red receptacle of which bears the fruitlets within its cavity, and the strawberry with a fleshy, sweet-tasting, red receptacle bearing the fruitlets in the form of achenes on its surface. Fruits of this kind are known as **Pseudocarps** or as accessory or anthocarpous fruits in contradistinction to true fruits, i.e., fruits developed from the pistil alone. To this class also belong still other forms of fruits of entirely different morphological structure, as, for example, the fig and the pineapple. These consist of individual fruits consolidated so as to form fleshy aggregates known as **Multiple Fruits** or collective fruits.

Another difficulty, in giving a satisfactory definition of a fruit and gaining a general idea of the forms of fruits, lies in the fact that some flowers have but one pistil and develop but one fruit, while others have several pistils. Fruits developed from the latter are known as **Aggregate Fruits**. According to this definition the pseudocarps of the rose and strawberry are also aggregate fruits since the fruitlets belong to a single flower.

A single fruit may also be developed from a several-celled pistil and at full maturity may split into several parts, each of which may be regarded as a single fruit. The fruits of the *Umbelliferæ* are of this character.

From what has been said it is clear that an extension of the meaning of the term " fruit " is highly desirable and the classification of fruits should be based chiefly on their origin from one or several leaves and on their methods of separation from the axis, or of opening to liberate the seeds.

According to G. BECK,[1] the fruit may be defined " as that specially metamorphosed organ of the plant which encloses the seeds until maturity and then either scatters them or else is separated from the plant with them ".

---

[1] G. R. v. BECK: Versuch einer neuen Classification der Früchte. Verhandl. k.k. Zool. Bot. Gesell. Wien, 1891, 307–312.

The following classification of fruits together with explanations of the morphology is by Beck:

I. Simple Fruits. Formed from one flower.
  A. Dehiscent Fruits. The fruits open (dehisce) and distribute the seed.
    1. Apocarps, or Simple Fruits. Fruits formed from one fruit leaf.
      (a) *Follicle*. The dehiscence is by one suture. A follicle may be dry (e.g., larkspur) or fleshy (e.g., peony); the milkweed is an example of a double follicle.
      (b) *Legume*. The dehiscence is by both the ventral and dorsal suture. A legume may be dry (e.g., vetch), fleshy (e.g., certain beans), or woody (e.g., *Proteaceæ*).
      (c) *Utricle*. The dehiscence is irregular (e.g., duckweed).
    2. Syncarps, or Compound Fruits. Those formed from two or more, more or less united fruit leaves. They are dehiscent in various ways.
      (d) *Capsule*. The opening of the fruit leaves is longitudinal and may be through a dorsal suture (loculicidal), through the walls, etc. The pods of Crucifers are capsules.
      (e) *Pyxis*. The dehiscence is through a line cut around the fruit so as to form a lid (e.g., *Hyoscyamus*).
      (f) *Pore Capsule*. Dehiscing through pores (e.g., poppy).
      (g) *Utricle*. The dehiscence is irregular (e.g., *Chenopoidum*).
  B. Indehiscent fruits. Fruits closed, deciduous, or certain parts inclosing the seeds deciduous.
    3. Apocarps or Simple Fruits (Monocarps). Fruit closed, formed from one fruit leaf.
      (h) *Nut*. Pericarp dry (leathery, horny, etc.), winged or not winged or else with a fleshy hull (e.g., rose, strawberry).
      (i) *Simple Stone Fruit (Drupe)*. Pericarp with a fleshy outer and a hard woody inner layer (e.g., peach).
      (j) *Simple Berry*. Pericarp fleshy (e.g., barberry, tamarind).
    4. Jointed Apocarps or Simple Fruits. The fruit is formed from one fruit leaf and breaks up into several, mostly one-seeded, closed parts or pericarps.

(*k*) *Jointed Pod* or *Loment.* Breaking crosswise into one-seeded joints (e.g., *Acacia*).

(*l*) *Bordered Pod* (Craspedium). Breaking crosswise into one-seeded joints, but the dorsal and ventral sutures remain as borders (e.g., *Entada*).

5. Schizocarpous Syncarps (Schizocarps). The fruit is formed from two or several fruit leaves and breaks up into several closed parts, or mericarps.

(*m*) *Compound Nut.* The one-seeded closed halves separate from the fruit leaves (e.g., *Labiatæ, Asperifoliæ*).

(*n*) *Jointed Pod.* Two consolidated fruit leaves separate transversely into one-seeded parts (e.g., radish).

(*o*) *Cremocarp.* Two or several fruit leaves separate as closed individuals (e.g., *Umbelliferæ, Galium, Malva.* The fruit of the maple is a winged form known as a *Samara*).

6. Closed Syncarps (Polycarps).

(*p*) *Achene.*[1] Pericarp dry. Fruit inferior (e.g., *Compositæ*); if superior it is known as a *Caryopsis* (e.g., cereal grains) or *Glans* (e.g., acorn).

(*q*) *Compound Stone Fruit* (Syncarpous Drupes). Outer pericarp fleshy, succulent, leathery, or fibrous; endocarp firm, often woody (e.g., cocoanut, buckthorn, walnut, apple, crowberry).

(*r*) *Berry* (Baccate Syncarp). Pericarp fleshy, succulent; epicarp thin:

Berry, superior......................Uva (e.g., grape).
Berry, inferior.................Bacca (e.g., blueberry).

Epicarp firmer and thicker:

Berry, superior.........Hesperidium (e.g., citrus fruits).
Berry, inferior................Pepo (e.g., *Cucurbitaceæ*).
Berry, cross-partitioned.....Balausta (e.g., pomegranate).

II. Multiple Fruits. Formed from two or more flowers.

7. Cones or Strobiles. Multiple fruit usually deciduous, scattering the seed (e.g., pine).

8. Consolidated Fruits. Fruits grown together in various ways (e.g., double berries of *Lonicera*, mulberry, pineapple).

---

[1] Many true achenes, also the caryopses of cereals, are apocarpous and belong properly under 3. (A. L. W.)

9. Syconia or Hypanthodia. The numerous fruits are free but separate together (e.g., fig, juniper berry, burdock, cotinus).

The fruit wall is known as the **Pericarp** or **Fruit Coat**. In many cases three more or less distinct layers are evident, each with a different histological structure and a correspondingly different physiological function. These three typical layers are especially well marked in the plum. The thin outer skin characterized by the bluish bloom (wax) is the **Epicarp** or **Exocarp**, the sweet fruit flesh, or middle fruit layer, is the **Mesocarp**, the hard shell of the stone forming the inner fruit layer is the **Endocarp**. The endocarp serves chiefly to protect the seed with its thin skin, or spermoderm. An equally sharp differentiation of the layers is found in the cocoanut. The mesocarp of this fruit is fibrous and yields a well-known fiber material known as coir; the endocarp is made up of lignified, strongly thickened, sclerenchyma elements which are either isodiametric, forming typical stone cells, or elongated.

In berries and many capsules, on the other hand, the endocarp is reduced to a single cell layer with the characters of an epidermis. Often a sclerenchymatous endocarp has an epidermis-like layer adjoining the cavity of the fruit.

The mesocarp in very many fruits is a thin-walled parenchyma, the cells of which may be rich in contents of a great many kinds. In the case of juicy fruits, the cells contain water in which sugar and other materials are held in solution; in other cases they may contain other carbohydrates, fatty oil, tannin substances, etc. Many fruits, characterized by their odor or taste, the so-called aromatic fruits, contain essential oils in special secretion cavities. Fruits containing a milky fluid have a system of latex tubes, the chief members of which accompany the vascular bundles. A very common material is calcium oxalate, which may be in the form of single crystals, crystal clusters, or raphides (needle crystals in bundles). Owing to the presence of vascular bundles, stone cells, stone cell groups, separating layers, etc., the structure of the mesocarp may be quite complicated. VOGL[1] states that in the transformation of the mesocarp it often happens that the endocarp and certain elements of the fruit cavity, such as the conducting elements and placentæ, develop into a succulent tissue and form, together with the inner parenchyma of the mesocarp, a mass of loosely united or partly isolated, succulent, thin-walled, spheroidal cells known as the fruit pulp. The epicarp forms, as a rule, an epidermis with stomata and often also with trichomes. Sometimes the cells show a palisade-like development.

---

[1] Arzneikorper, 135.

II. The Seed.

The term "seed" is applied to that final product of the generative activity of the plant which contains the germ or embryo, i.e., the future plant in an undeveloped condition. The chief constituents of the seed are the hull, or shell, and the kernel, or meat. In order to understand the structure of the different parts, especially the kernel, it is necessary to follow the principal stages in the development of the seed from its first beginnings.

On a definite part of the inner wall of the ovary, known as the **Placenta**, there is formed a lump of tissues which (after fertilization) finally develops into the seed. This initial organ is the **Ovule**. It is joined to the placenta either directly at a broad place of attachment, in which case it is sessile, or by means of a slender thread of tissues known as the **Funiculus**[1] (Figs. 201 and 202, *f*). The bulk of the ovule consists of a delicate meristematic tissue known as the **Nucellus** (Figs. 201 and 202, *n*). Enveloping the nucellus are one or two—very rarely three—coats, the **Integuments** (Figs. 201 and 202, *ai*, *ii*). These are continuous except for a narrow canal at the apex, known as the **Micropyle** (*m*), which ends at the apex of the ovule and furnishes communication between that and the outer air. The vascular bundle of the funiculus enters the ovule and ends at the base of the nucellus. This place, often well marked in the seed, is the **Chalaza** (*ch*). The place where the funiculus joins the ovule or, in case the funiculus is not developed, where the placenta and ovule are united, is also very distinctly marked in the seed and is known as the **Hilum**. Some plants have an accessory coat, the so-called **Arillus** or **Aril**, which springs either from the placenta or the funiculus. Mace, the arillus of the nutmeg, is a well-known example.

There are three leading types of ovules, all of which are illustrated in Fig. 202. If the nucellus is straight and the micropyle and the hilum are at opposite ends, the ovule is **Orthotropous** or **Atropous** (*A*, *C*); if, however, the ovule is bent at the base of the nucellus and the funiculus is grown to it its entire length, it is **Anatropous** (*D–G*). The part of the funiculus which is joined to the ovule and is evident also in the mature seed as a more or less pronounced ridge or line is known as the **Raphe.**

---

[1] M. Dahmen: Anat.-phys. Untersuchungen ueber den Funiculus des Samens. Berlin, 1891.

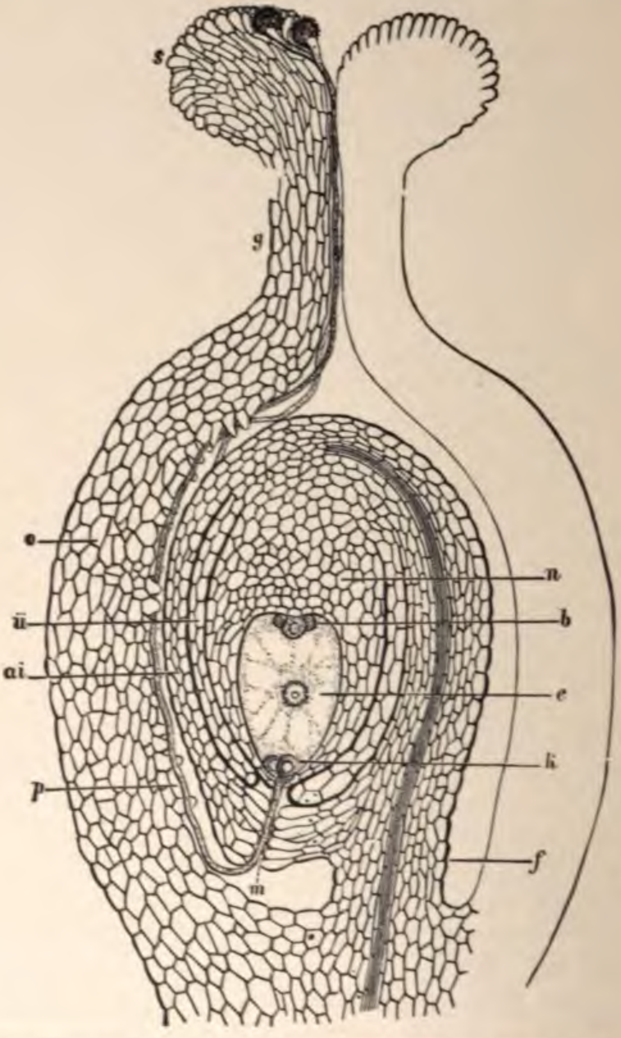


FIG. 201. Diagrammatic Longitudinal Section of Pistil with Anatropous Ovule, at Time of Fertilization. (LUERSSEN.)

o ovary; *s* stigma with two pollen grains sending out tubes one of which *p* has entered *e* the embryo sac through *m* the micropyle; *b* antipodal cells; *f* funiculus with vascular bundle; *ai* outer integument of ovule; *ii* inner integument.

If the ovule is bent it is **Campylotropous** (*B*). According to the direction in which it stands, relative to the placenta, the ovule may be upright

(*B*), horizontal (*C*) ascending (*D*, *E*), or pendent (*F*, *G*). The raphe may be ventral, i.e., turned toward the placenta (*D*, *F*), or dorsal, i.e., turned away from it (*E*, *G*).

As regards the development of the embryo, the following brief description will be sufficient for our purpose. The embryo sac, a cell of abnormal size, contains a nucleus which splits up into two parts, one of which moves to the apex of the nucleus, the other to the opposite end. Each of these two parts in turn divides into four parts, and three of the four parts remain at their respective ends and become encased in membranes, thus forming cells. The fourth part of one group, however, joins the fourth part of the other to form a central kernel (Fig. 201, *e*). Of the three cells at the apex one becomes the **Oosphere**, while the other two are known as **Synergids** or **Synergidæ**. From the oosphere, after fertilization, is developed the embryo. The cells at the base of the embryo sac are known as **Antipodal Cells.**

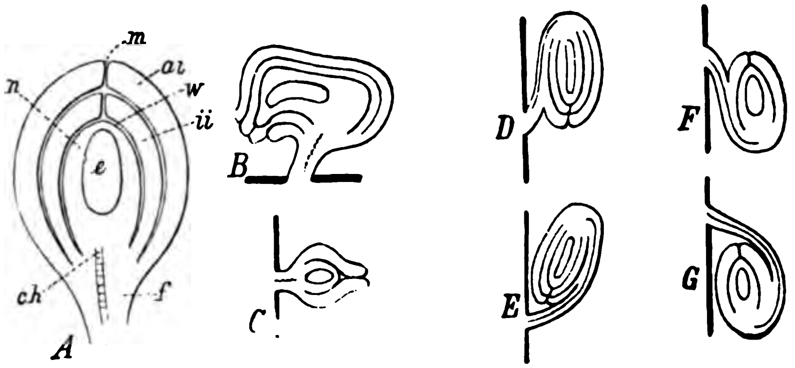


FIG. 202. Diagrammatic Longitudinal Sections of Different Forms of Ovules. (PAX.) *A* orthotropous ovule with two integuments: *f* funiculus; *ch* chalaza; *n* nucellus; *ai* outer integument; *ii* inner integument; *m* micropyle; *e* embryo sac.—*B* upright campylotropous ovule.—*C* horizontal orthotropous ovule.—*D* ascending anatropous ovule with ventral raphe.—*E* same as last, but with dorsal raphe.—*F* pendent anatropous ovule with ventral raphe.—*G* same as last, but with dorsal raphe. The dark lines in *B–G* mark the position of the placenta.

In the formation of the embryo from the oosphere three different types of development and three forms of seed, dependent on the differences in the relative development of the embryo sac and the nucellus, may be distinguished. While the embryo is being developed from the oosphere, there is formed in the embryo sac alongside of or about the embryo a tissue containing reserve material, such as proteid matter, carbohydrate, fat, etc., usually in considerable amount. This is the **Endosperm,** or **Albumen.** If it remains a somewhat bulky tissue until maturity, the embryo itself being rather small, the seed is said to be endospermic or albuminous (Fig. 203, *E*, *F*, *G*, and Fig. 204, *D*). If, however, the endosperm is used up in forming the embryo and the tissue of the nucellus is also displaced, the seed within the hull consists only of the large embryo and is said to be exalbuminous (Fig. 203, *C*, *D*, *H–M*). Well-known examples of exalbuminous seeds are legumes such as peas, beans, etc. It must be stated, however, that traces of endosperm or nucellus may very often be found by a microscopic examination in exalbuminous seeds.

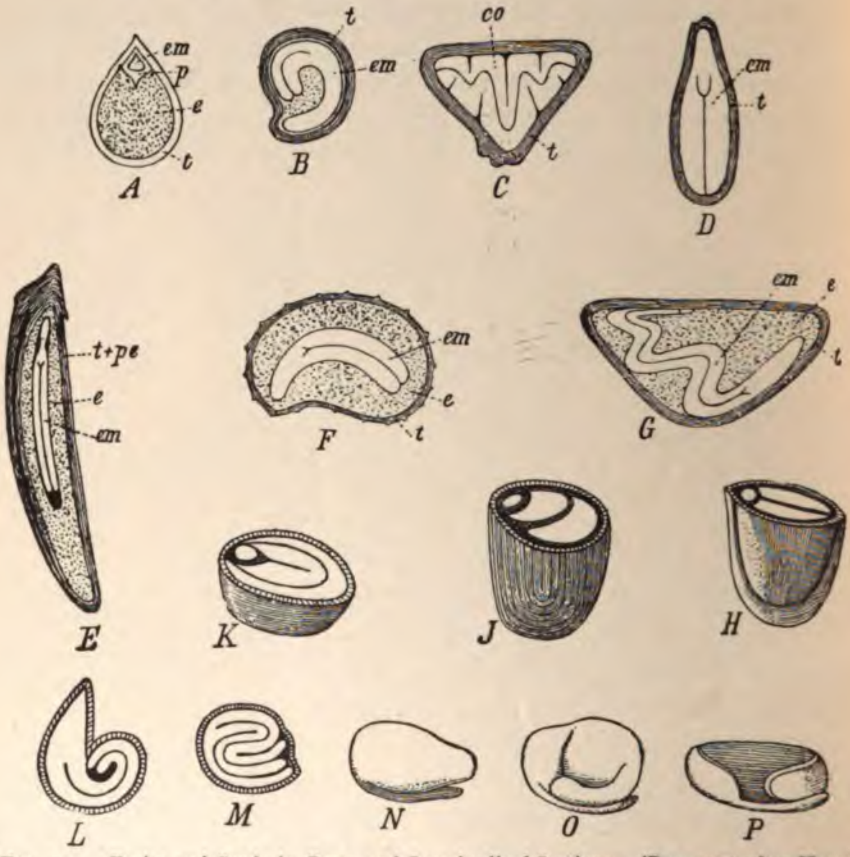


FIG. 203. Fruits and Seeds in Cross and Longitudinal Sections. (PAX, part after HARZ.) *A Saururus Loureiroi; B Sesuvium Portulacastrum; C Fagus sylvatica; D Amygdalus communis; E Peucedanum Palimba; F Papaver somniferum; G Convolvulus arvensis; H Cheiranthus Cheiri; J Alliaria officinalis; K Brassica; L Bunias; M Heliophila; N* embryo separated from *Acer Pennsylvanicum; O* from *A. platanoides; P* from *A. Negundo.* —*co* cotyledons; *em* embryo; *pe* pericarp; *t* spermoderm. In *E*, *F*, and *G*, *e* endosperm; in *A*, *p* endosperm and *e* perisperm.

The so-called hyaline layer occurring in certain seeds (e.g., cereal grains) consists mostly of remnants of the nucellus.

If the tissue of the nucellus remains active, increases in size, and acts as a storehouse for reserve material, it is known as the **Perisperm** (Fig. 203, *A*). The larger part of the black-pepper berry consists of perisperm.

The **Spermoderm**, **Testa**, or **Seed Coat** is developed from the integuments of the ovule. If two distinct layers separated from one another are recognizable, the outer is known as the testa proper, the inner as the **Tegmen**.

The **Embryo** (with some exceptions which are not of interest to us in this connection) consists of axis and seed leaves. The axis is differentiated into a root part, or **Radicle**, the point of which is always directed toward the micropyle (in the case of anatropous seeds, also toward the hilum), and an axis proper, or **Plumule**, with embryonic leaves (Fig. 32). Attached to the axis are one, two, or several seed leaves or **Cotyledons**. According to the number of cotyledons, **Phenogams**, or flowering plants, are divided into two classes: **Monocotyledons** (with one cotyledon) and **Dicotyledons** (with two or more cotyledons). The embryos of conifers have several—up to sixteen—cotyledons. That part of the axis below the cotyledons which, like the stem, grows upward (negatively geotropic) and often lifts the cotyledons from the ground, is known as the hypocotyledonary stem or **Hypocotyl**.

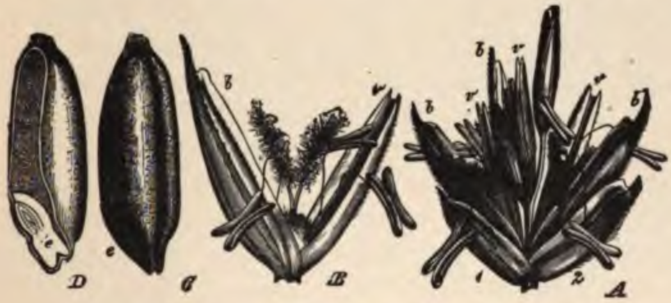


FIG. 204. Wheat. (SCHUMANN.)

A spikelet: *1* and *2* empty glumes; *b* flowering glumes; *v* palets.—*B* single flower.—*C* and *D* fruit: *e* embryo.

Now that we have learned the morphological characters of fruits and seeds we will take up the microscopic investigations of certain examples of economic importance.

III. Microscopic Investigation of Typical Examples of Technical Fruits and Seeds.

WHEAT.[1]

The cereals, including wheat, rye, barley, oats, maize, rice, and millet, are the most valuable of vegetable products since they supply us with the food necessities, flour and bread. In a purely technical sense they also are of great importance, as they yield starch, glucose, alcohol, proteids, oil, etc., also certain valuable by-products. Although an exhaustive treatment of the structure of the cereals belongs to works on the microscopy of foods, the structure of wheat is here described for the purpose of acquainting the technical microscopist with the general characters of the group. He will learn, among other things, what part of the grain yields starch, a product whose importance we have already considered.

The term wheat, as ordinarily used, refers to common wheat (*Triticum sativum* var. *vulgare* Vill. Hackel), the different varieties of which are very extensively cultivated.[2]

The fruit of common wheat (Fig. 204, *D*, *C*), which when fully ripe drops out of the chaff (Fig. 204, *A* and *B*, *h*, *r*), is elongated ovate, bluntly three-angled, often somewhat swollen. On the dorsal side the grain is rounded or obscurely blunt-keeled, becoming flattened toward the base, where, over the embryo, the surface is wrinkled. On the ventral side there is a longitudinal cleft, behind which, as may be seen in cross-section, is a cavity. A beard of fine short hairs clothes the apex. The ground color is yellow-brown, varying to light yellow-gray and to brown-red. The fruit is one-seeded, superior, with the fruit coat (pericarp) grown to the seed coat (spermoderm), and is therefore a caryopsis (see p. 327). A longitudinal section (Fig. 204, *D*) shows at the base the small embryo, which is readily distinguished from the starchy endosperm by its fatty appearance.

---

[1] [illegible] T. F. Hanausek: Die Nahrungs- und Genussmittel, [illegible] Nobbe: Landwirtschaftliche Samenkunde. Berlin, [illegible] Die Stärke und die Mahlprodukte, 91. F. Kudelka: [illegible] Entwickelung und den Bau der Frucht- und Samenschale unserer Cerealien. Inaug.-Diss. Berlin, [illegible] Moeller: Mikroskopie der Nahrungs- und Genussmittel. Berlin, [illegible] Tschirch u. Oesterle: Anatomischer Atlas. Leipzig, 1895, [illegible] Vogl: Die wichtigsten vegetabilischen Nahrungs- und Genussmittel. Wien, [illegible] Winton: Microscopy of Vegetable Foods. New York, 1915, 65. [illegible] Verfälschungen. Leipzig, 1887, 335 (Mehle).

[2] [illegible] (1) naked wheats, including common wheat (*T. sativum* var. *vulgare* Vill. Hackel), Polish wheat (*T. Polonicum* L.), English wheat (*T. sativum* var. *turgidum* L. Hackel), macaroni wheat (*T. sativum* var. *durum* [illegible] Hackel) and dwarf wheat (*T. sativum* var. *compactum* Host. Hackel); (2) chaffy wheats, including spelt (*T. sativum Spelta* L. Hackel), emmer (*T. sativum* var. *dicoccum* (Schrank) Hackel) and einkorn wheat (*T. monococcum* L.). The naked wheats readily separate from the chaff in threshing while the chaffy wheats are closely invested with the chaff [illegible]

It thus appears that the fruit is made up of three parts: (1) the bran coats, consisting of united pericarp, spermoderm, and perisperm; (2) the endosperm; and (3) the embryo.

The structure of the bran coats must be studied in transverse and longitudinal sections. Cross-sections should be cleared by placing in chloral hydrate or dilute potash; longitudinal sections usually appear very distinct in water. After making a systematic study of the fruit, it is excellent practice to identify the individual tissue elements as found in wheat bran. In this way one soon acquires considerable facility in distinguishing the various characteristics. The cross-section (Fig. 205) displays three sharply defined portions: (1) an outer coat made up of different tissues, the united pericarp, spermoderm, and perisperm (*ep–n*); (2) a layer of large thick-walled cells rich in contents, the aleurone layer (*Kl*); and (3) the starch-containing cells of the endosperm (*st*).

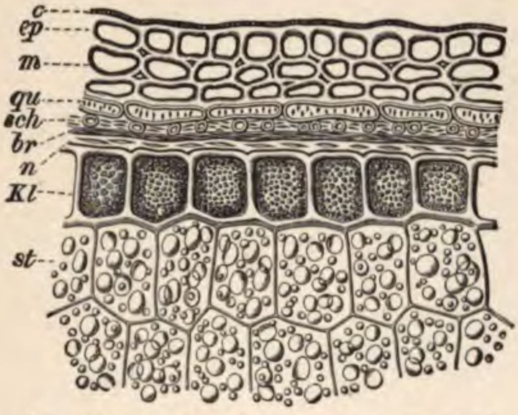


FIG. 205. Wheat in Cross-section. (TSCHIRCH.)

Pericarp consists of *ep* epicarp with *c* cuticle, *m* mesocarp, *qu* cross-cells, *sch* tube cells, *br* two layers of spermoderm; *n* perisperm; endosperm consists of *Kl* aleurone cells and *st* starch cells.

The pericarp consists of an outer epidermis, or **Epicarp** (*ep*), covered with a thin cuticle (*c*), the **Mesocarp**, or middle layer (*m*), a very characteristic layer of transversely elongated cells, known as **Cross-cells** (*qu*), and on the inner side of the last the **Tube Cells**, constituting the remnants of the inner epidermis of the pericarp, the endocarp. Then follow two cell layers forming the **Spermoderm** (*br*), and a single layer of hyaline cells forming the **Perisperm**, or nucellar tissue (*n*).

The **Epicarp** consists of tabular cells which in cross-section (Fig. 205, *ep*) are rectangular and show a thick outer wall. In surface view the cells are elongated (Fig. 206, epi^2), except at the apex of the grain, where they are polygonal (epi^1), and have straight beaded (i.e., pitted) walls. A thin cuticle (*c*) overlies the layer. At the apex the hairs of the so-called beard occur in considerable numbers between the epidermal cells. These hairs (Fig. 206, *t*) are unicellular, straight, or somewhat crooked, and vary up to 1 mm. long. The rounded base has a wide lumen and is sometimes geniculate and distinctly porous. Above the base the hairs are in some cases enlarged, but further on they contract quite abruptly

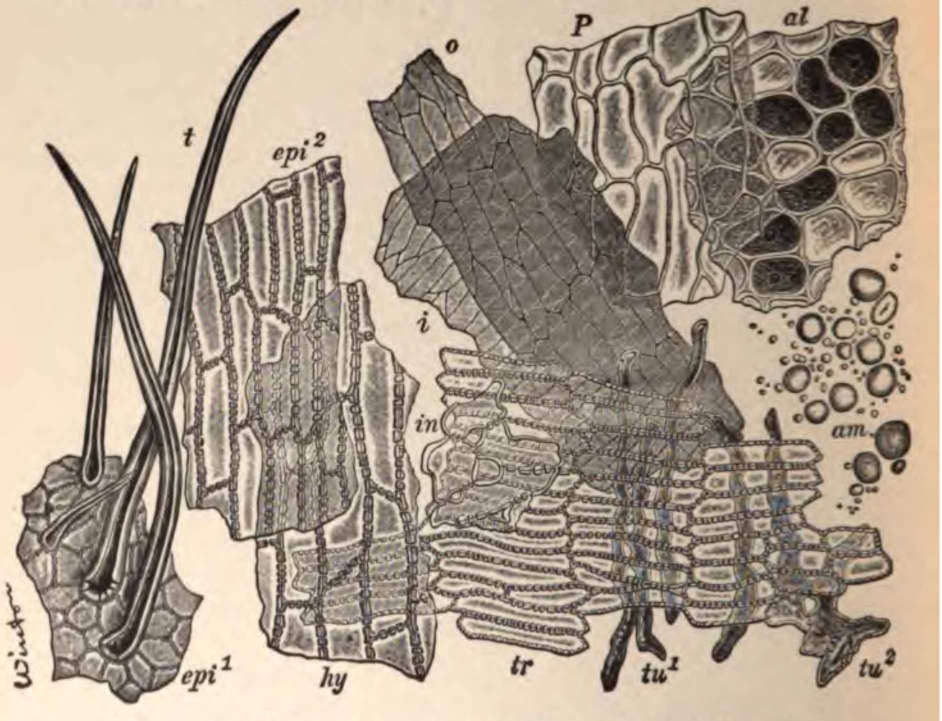


FIG. 206. Wheat. Elements in Surface View. ×160. (WINTON.)

epi^1 epicarp at end of grain with *t* hairs; epi^2 epicarp on body of grain; *hy* hypoderm (first layer of mesocarp); *in* intermediate cells; *tr* cross-cells; tu^1 typical tube cells; tu^2 tube cells passing into spongy parenchyma; *o* outer layer of spermoderm; *i* inner layer of spermoderm; *P* perisperm; *al* aleurone cells; *am* starch grains.

into a narrow shaft, with a very narrow lumen, which ends in a sharp point. Except near the base the thickness of the wall is greater than the breadth of the lumen. The hairs are of great value in the diagnosis of wheat flour. Those found on the end of the rye kernel have a broad lumen which extends nearly to the apex. In general it may be said, as was first noted by WITTMACK, that wheat hairs have thick walls and a narrow lumen, while rye hairs have relatively thin walls and a broad lumen.

Beneath the epicarp lies the **Mesocarp,** consisting of two to three layers of cells elongated parallel to the axis of the fruit (Fig. 205, *m*; Fig. 206, *hy*). These cells, as well as the epidermal cells, are richly porous, the pores being quite different from those found in the corresponding cells of rye, a point first noted by the author.[1] VICTOR BERTHOLD[2] describes the mesocarp cells of wheat as shorter, thicker-walled, and more richly pitted than those of rye, but does not note the peculiarities of the pores. If a surface fragment of this layer is treated with dilute potash, the cell walls become swollen, and we note that in wheat the portions between the pores have distinct right angles and are bounded by straight lines, furthermore that the boundary line parallel to the longitudinal direction of the cells is straight, although broken; in rye the portions of the walls between the pores are quite irregular, forming partly rounded, partly rhombic figures, and the boundary line on each side is almost wavy. These differences in the pits are even more pronounced in the cross-cells.[3]

In many coarse wheat products we find, in greater or less abundance, irregular parenchyma cells (Fig. 206, *in*) with short projections which unite the individuals forming a kind of spongy parenchyma with rather large rounded intercellular spaces. This spongy tissue, designated by TSCHIRCH the **Intermediate Layer**, occurs here and there beneath the mesocarp, chiefly in the cleft.[4]

Next follows the layer of **Cross-cells** (Fig. 205, *qu*; Fig. 206, *tr*). These cells are among the most important and striking of the diagnostic elements. They are elongated, very richly pitted, and the longitudinal axes are perpendicular to those of the mesocarp, or, in other words, the cells cross those of the mesocarp at right angles, hence the name cross-cells. They are arranged side by side, with some regularity, in rows, and the end walls, which are sometimes indistinctly pitted, are closely united, with few and very insignificant intercellular spaces. The end walls of the cross-cells of rye are never pitted, rather thick, rounded, and show very distinct intercellular spaces. These cells are shorter in rye than in wheat, and the side walls show differences in the thickening similar to those noted for the epicarp and mesocarp.[1] In some parts the cells are but slightly elongated, have rounded pores, and are not unlike thin-walled sclerenchyma cells. The walls are lignified. As may be seen in cross-section, the inner walls are thicker than the outer and the pits on the radial walls are large, rounded, and, as noted by VOGL, resemble windows.

---

[1] T. F. HANAUSEK: Zur mikroskopischen Unterscheidung des Weizen- und Roggenmehles. Ztschr. allg. Österr. Apoth. Ver. 1887, **25**, 143.

[2] Ueber den mikroskopischen Nachweis des Weizenmehles im Roggenmehl. Ztschr. Landw. Gewerbe, 1883.

[3] See VOGL: Die wichtigsten vegetabilischen Nahrungs- und Genussmittel, Fig. 46, p. 82.

[4] This tissue has only recently been described. I myself have often wondered to what "foreign" material these spongy parenchyma cells, occurring in bran, belonged. Certain kinds of flour, as for example No. 7. (see p. 342), contain them in even greater numbers than bran.

Surface mounts of the outer bran coats of authenticated specimens of wheat and rye are valuable aids in distinguishing the cross-cells of the two cereals. In making comparisons the treatment of the unknown materials with reagents must of course be the same as was employed in preparing the standard mounts.

The inner layer of the pericarp or endocarp consists of **Tube Cells** (Fig. 205, *sch*; Fig. 206, tu^1) which do not form a continuous tissue, but usually occur singly beneath the cross-cells. These cells are elongated parallel to the axis of the fruit, and therefore at right angles to the cross-cells, and form long (up to 310μ), mostly thin-walled, irregularly knotty or wavy closed tubes with offsets.

In cross-section we next note a narrow stripe consisting of two simple layers of cells (Fig. 205, *br*). This is the **Spermoderm**, or **Seed Coat**. The outer layer (Fig. 206, *o*) is colorless, the inner (*i*), orange-yellow or brown. In both, the cells are thin-walled, elongated, but the elongation in one layer is in a different direction from that in the other, or, in other words, the cells of the two layers cross one another. The brown layer is easily found in coarse mill products and is not rare in the finest flour, In connection with this tissue layer we should note a very peculiar element, which, in the examination of mill products, may give rise to various errors. We find in medium and coarse products, often in abundance, brown, thick, opaque strings to which are attached, on one or both sides. shreds of colorless or yellow ill-defined tissues. Were it not for these latter tissues these strings might be said to resemble the so-called oil ducts of umbelliferous fruits, for which indeed they have been mistaken by inexperienced observers. As a matter of fact umbelliferous fruits (e.g., *Caucalis*) do occur in wheat and are separated in the screenings, but the microscopist will observe that these brown pigment strings occur in all mill products of wheat, even very fine flour, and he is forced to the conclusion that they are a constituent of the kernels. If he compares them with the oil ducts of umbelliferous fruits, he will notice that the latter differ from them in that the shreds of accompanying tissue are made up of well-defined cells. By this characteristic it is possible, almost at the first glance, to distinguish the pigment strings from oil ducts. The pigment string is located behind the cleft, quite near the seed coat, and consists of brown cells. According to TSCHIRCH, this string belongs to the next layer (perisperm), which on ripening commonly separates from the aleurone layer, thus forming a cavity between the two. The mesocarp also is usually torn in this part.

---

[1] In distinguishing the two cereals I rely chiefly on the appearance of the side walls. These walls in wheat are thicker and much more sharply and distinctly beaded than in rye. (A. L. W.)

The next layer is the remnant of the nucellus and is therefore a true **Perisperm**. This tissue is made up of a layer of colorless cells the outer and inner walls of which are so strongly thickened that the lumen, as seen in cross-section (Fig. 205, *n*), is reduced to a narrow cleft, or a mere line, while the radial walls, on the other hand, are very thin. Only in carefully prepared surface mounts, especially after treatment with chloral or potash, is this layer evident (Fig. 206, *P*). As seen in cross-section, it might be mistaken by the beginner for two layers, since the narrow lumen, extending the entire breadth of the cell, has the appearance of a cell wall.

In rye the cells of the perisperm are elliptical in cross-section, not rectangular, distinctly separated from one another, and the walls are more or less distinctly laminated and mucilaginous.

The **Endosperm** is divided into two parts: (1) the **Aleurone Layer**, consisting of a single cell layer, and (2) the **Starch Parenchyma**, forming the bulk of the grain.

The **Aleurone Layer**, formerly known as the **Gluten Layer**,[1] consists of large thick-walled colorless cells which are quadrilateral in cross-section (Fig. 205, *Kl*) and polygonal in surface view (Fig. 206, *al*). They contain oil globules (the "aleurone grains" of JOHANNSEN) in a ground substance of proteid matter. Sometimes one of the cells is divided by a tangential wall into two cells, of which the inner, as shown by A. VOGL, contains a small amount of starch in fine granules. The aleurone layer, with its thick-walled cells and granular contents, is a highly characteristic tissue element of all the cereals. Very similar elements occur in many oil seeds.

---

[1] Both terms are misnomers, as the cells contain neither gluten nor aleurone grains. See JOHANNSEN: Studien über die Kleberzellen der Getreidearten. Bot. Centbl. 1883, **15**, 305; also BRAHM and BUCHWALD: Botanische und chemische Untersuchung an prähistorischen Getreidekörnern aus alten Gräberfunden. Ztschr. Unters. Nahr. Genussm. 1904, **7**, 12. (A. L. W.)

A. TSCHIRCH [1] describes the appearance and deportment of the so-called "aleurone grains" (really fat globules in a proteid network) as follows: "The aleurone grains are rounded or variously distorted and bowed, and are not colored by iodine. They are very small (1–3μ), but are rendered distinct if a section of the dry material is mounted in alcohol or a solution of osmic acid. Even in water or iodine solution they preserve their form. Sulphuric acid and potash dissolve them, leaving undissolved a fine network which is colored yellow with iodine and brown with osmic acid. If the section is mounted in olive oil instead of water, the network is apparent and the 'aleurone grains' appear as cavities. In the corners of the meshes rounded or distorted knots are evident. These appear to be oil globules. If sulphuric acid is allowed to act on the section previously mounted in water, very small drops of fatty oil emerge from the network."

The **Starch Parenchyma**, forming the larger part of the endosperm, consists of large, very thin-walled cells containing starch grains (Fig. 206, *am*). The characters of wheat starch have already been described (p. 38). After treating carefully prepared sections of the strictly fresh fruit with very dilute iodine solution, it may be seen that the starch grains are embedded in a meager ground tissue of proteid matter. If a portion of the endosperm of the wheat kernel is scraped off, avoiding fragments of the aleurone layer, and rubbed up with water on a slide, small spindle-shaped strings are formed which, by means of a cover glass, may be rolled back and forth, also drawn out and flattened. This is the **Gluten,** which forms the chief part of the proteid matter of white flour. The proteid matter of the aleurone layer occurs in much smaller amount—a fact long known to milling experts who distinguish the flour gluten or true gluten from the cell gluten or aleurone. The property of the gluten to form strings when rubbed with water, due to its great cohesion and its freedom from a tendency to form an emulsion, a property peculiar to wheat gluten and in a much lesser degree to maize gluten, but not to rye gluten, is the basis of a time-honored practical test for wheat flour (see p. 346).

---

[1] Anatomischer Atlas, 153.

The **Embryo,** or **Germ,**[1] is situated in the basal part of the fruit on the dorsal side. It consists of (1) the **Radicle,** inclosed in a special sheath, the **Coleorhiza** (Fig. 207, *co*; see also Fig. 32, *ws*); (2) the **Plumule,** inclosed in a cap-shaped leaf, the **Coleophyllum,** now regarded as the cotyledon; and (3) the shield-shaped **Scutellum** (Fig. 207, *sc*), formerly regarded as the cotyledon, which lies on the side adjoining the endosperm and, by means of an epithelial layer of palisade cells (*C*), sucks from it the nutritive matter for the use of the plantlet. Almost all the cells of the germ are very rich in fatty oil.

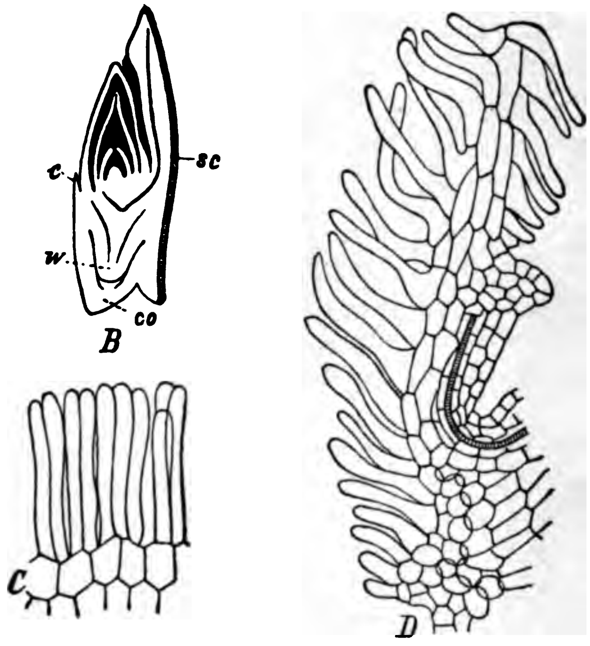


FIG. 207. Embryos of Grasses. (HABERLANDT.)

B embryo of wheat in longitudinal section: *w* radicle covered by *co* coleorhiza; *sc* scutellum, the absorbing layer adjoining the endosperm is shaded; *e* epiblast (according to HACKEL an absorptive second cotyledon).—*C* absorbing cells of the scutellum.—*D* longitudinal section of isolated scutellum of *Briza minor.*

---

[1] A detailed description of the wheat germ is given by AUGUST SCHLICKUM in his Dissertation (Marburg, 1895), "Morphologischer und anatomischer Vergleich der Kotyledonen und ersten Laubblätter der Keimpflanzen der Monokotylen," 56–74.

Fragments of the germ occurring in mill products are strikingly characterized by the regularly arranged cubical thin-walled cells.

We have learned from the foregoing description the microscopic characters of the grain of a naked cereal, i.e., a cereal not enveloped by chaff, also the characters which distinguish rye from wheat. We will now turn to the practical application of this knowledge and take up the examination of wheat flour, so far as it lies within the province of the microscopist. It should here be stated that in this section the subject will be considered from the didactic standpoint for the purpose of acquainting the student with the general methods—exclusive of purely chemical—employed in the examination of flour. Further treatment of the subject will be found in works on the microscopy and analysis of foods.[1]

THE EXAMINATION OF FLOUR WITH REFERENCE TO ITS IDENTITY AND PURITY.

Strictly speaking, wheat flour is the mill product consisting of all the elements constituting the fruit, including the husk or bran coats. Since, however, the bran is less digestible than the endosperm, and the germ, because of its oil, makes the flour greasy and diminishes its keeping qualities, the modern miller strives to eliminate these parts as completely as possible, so that the product consists almost entirely of the elements of the endosperm. Since this latter part of the grain, in a ground condition, is white or yellow, the color is an important factor in grading flour. It is also clear that the finest and whitest flour must contain very little of the bran elements and must consist chiefly of starch and gluten. According to the content of bran, which in turn is dependent on the details of the process of manufacture, wheat flour is graded in Austro-Hungary by numbers (0, 1, 2, 3, 4, 5, 6, 7, 8, 8½, 8¾, 9, or 0–6), of which No. 0 is the best and purest and No. 9 the poorest and most impure.

The ground product also contains various weed seeds (fruits and seeds), as well as fungous threads and spores, in quantities varying according to the care taken in the purification of the grain. The identification of these impurities falls to the microscopist.

---

[1] VOGL: Die wichtigsten vegetabilischen Nahrungs- und Genussmittel. TSCHIRCH u. OESTERLE: Anatomischer Atlas. MOELLER: Mikroskopie der Nahrungs- und Genussmittel. Berlin, 2. Aufl. 1905. WINTON: Microscopy of Vegetable Foods. New York, 1915. Chemical methods are described in the following: KÖNIG: Die menschlichen Nahrungs- und Genussmittel. Berlin, 1905. LEACH: Food Inspection and Analysis. New York, 1914. Methods adopted by the Association of Official Agricultural Chemists. U. S. Dept. Agr., Bur. of Chem. Bull. 107, Revised Edition.

We will now describe the methods of investigation.[1]

1. **COLOR.**—The color of the dry flour is determined by observing both the loose and pressed surface, first with the naked eye, then with the lens. This property depends on the kind of wheat, the method and fineness of grinding, and the foreign matter present. The best grades are pure white, dazzling white, and white with a yellow tint, while the poorer grades are yellowish white, grayish white, and yellow. A jet-black background should always be used. This test also determines certain points with regard to the fineness and purity of the flour. Attention should be given to the amount, size, and distribution in the flour of the dark particles which influence the color of the product. These belong partly to the bran and partly to impurities. The coarser the flour, the more distinctly evident are these particles. Groups of smut spores appear as coal-black spots. In this examination the Weinzierl double lens is of service.

A sharp distinction in color is obtained by " pekarizing ", in which process a portion of the flour is "slicked" with a flour trier on a glass plate alongside of a standard flour. The test is rendered more delicate by carefully immersing the plate in water, and still more delicate by drying.

Bleaching with nitrogen peroxide or chlorine has greatly impaired the value of color tests in judging the purity and excellence of the product. This form of adulteration is detected by certain chemical methods.[2]

2. **MECHANICAL CONDITION.**—The grit or the granulation of the flour as determined by the hand, is a valuable indication of its mechanical condition. On this test A. v. VOGL states as follows: " The hand is plunged into the flour and as much of it as possible pressed in the fist. Normal flour can be easily pressed together, is loose, soft, uniformly homogeneous, and it should not contain firm, compact lumps or conglomerates, nor give a sensation of cold." If the flour remains in a ball after opening

---

[1] See T. F. HANAUSEK: Ueber die Untersuchung der Mehle. Österr. Chem. Ztg. 1899, 4. *Idem:* Ueber unser Mehl und Brod, von botan. Gesichtspunkten aus betrachtet. k.k. Gart. Gesell. Wien. Illus. Gart. Ztg. 1899, 4, 109–118. VOGL: Mehl in Codex alimentar. austriacus. Ztschr. Nahr. Unters. Hyg. Warenk. 1897 and 1898. *Idem:* Die wichtigsten vegetabilischen Nahrungs- und Genussmittel, 11.

[2] LEACH: Food Inspection and Analysis, 1914, 321.

the first, the water content is usually higher than the normal, in any case over 20 per cent.

The term "grit"[1] commonly refers to the fineness of the flour as regards the size of the individual granules of which it is composed. In this connection it should be noted, first of all, that in Austria-Hungary, flour of the better grades (No. 0–4) appears in two principal varieties.

The first variety is known simply as fine or smooth and is designated with its number, as, for example, "No. 1 fine", or "No. 1 smooth", etc. This designation means that the flour when rubbed between the fingers feels downy, slippery, and extraordinarily smooth, while in its other properties, such as fineness, color, content of bran, and ash, it corresponds to the type No. 1. It has then definite characters which can be accurately determined.

The second variety, known as "gritty", has quite different characters. Gritty flour consists of large coarse grains, feels rough, granular, and finely gritty, and when floated on a glass plate shows very distinctly the individual granules and therefore its finely gritty constitution. According to the size of these granules, the flour is designated gritty or double gritty, the grains in the latter being larger than in the first. This variety of flour is, however, of the same purity and quality and contains the same amount of ash as fine or smooth flour, and is designated by the same numbers (0–4) with the addition of "gritty" or "double gritty". The characters of this flour, like those of the first, can be recognized by the layman.

Gritty flour may also be easily recognized with a lens or a microscope. A. v. VOGL,[2] who has exhaustively treated the subject, remarks with regard to its detection as follows: "Under the lens double gritty and gritty wheat flour appear to be made up of small irregular granules which, when dry, do not cling together, but easily fall apart. The surface, smoothed by pressure, is uneven, as if finely granular and spongy—a character especially noticeable in double gritty, less so in gritty flour."

With the microscope we notice that smooth flour consists in large part of the isolated, often ruptured, cells of the endosperm and of the liberated contents consisting chiefly of starch grains. Gritty flour, on the other hand, consists chiefly of cell aggregates, the contents of which are in their original position and fill the cell lumens. Gritty and double gritty flour can be distinguished under the microscope by the size of the cell aggregates, which may be estimated by one with long experience or more accurately determined by measuring with the micrometer. Whether a grist yields gritty or smooth flour depends on whether the surface of the rollers is grooved or smooth.

---

[1] T. F. HANAUSEK: Ueber die Griffigkeit der Mehle. Österr. Chem. Ztg. 1900, No. 3.

[2] [illegible] wichtigsten vegetabilischen Nahrungs- und Genussmittel, 1899, 13.

A word with regard to the use of gritty flour. Bakers and confectioners are the chief consumers, while the public at large knows less of it. Experience has brought out the interesting facts that gritty flour takes up water more readily and that it yields a dough which rises better and becomes light and spongy on baking, while smooth flour often gives unsatisfactory results for reasons not well understood. The term "polished flour", sometimes used for smooth flour, is particularly expressive. Flour of this kind more easily becomes heated during grinding, thus swelling and mutilating the starch grains and often gives ununiform results on baking. Consumers generally do not like gritty flour, since they believe that the rough feeling is incompatible with the purity and excellence of the better grades. For example, a sample once submitted to me, owing to its harsh feeling, was suspected by the sender of containing sand. As a matter of fact it was gritty No. 1 flour, fully up to standard.

3. **ASH.**—A determination of ash in each sample of flour is advisable. This is carried out on 10 grams of the material by the usual process. Since the mineral constituents finally fuse to a glass, it has been recommended, in order to remove possible particles of carbon, to grind the charred mass as soon as it hardens into a compact lump, mix with a weighed amount of sand, and burn to whiteness. Usually, however, this procedure is not necessary.[1]

The determination of ash puts us in a position, first, to recognize the type of flour, and, second, to detect mineral admixtures such as sand. The presence of sand in appreciable amount is easily recognized by the gritty feeling when a small portion of the flour is rubbed between the teeth.[2]

---

[1] If a muffle furnace is used, the ash can usually be burned to whiteness at a heat below distinct redness without special treatment. The following is the method of the Association of Official Agricultural Chemists of the United States (U. S. Dept. Agr., Div. Chem., Bull. 46, revised edition, p. 23): "Char from 2 to 3 grams of the substance and burn to whiteness at the lowest possible red heat. If a white ash can not be obtained in this manner, exhaust the charred mass with water, collect the insoluble residue on a filter, burn, add this ash to the residue from the evaporation of the aqueous extract, and heat the whole to a low redness till the ash is white or nearly so." (A. L. W.)

[2] The addition of mineral matter to flour or cereal cattle foods is seldom if ever practiced in the United States. (A. L. W.)

VEDRÖDI[1] has made the observation that the ash content of a flour bears a definite relation to the degree of fineness. This observation has since been frequently corroborated by the author and others. The test for color, taken in conjunction with the determination of ash, furnishes us with an excellent means of determining with the greatest certainty the type to which a given sample of wheat flour belongs, or of detecting the admixture of different types, which is of very frequent occurrence.

The following is by VEDRÖDI:

No. 0 flour contains 0.20–0.34 per cent of ash.
“ 1 “ “ 0.35–0.39 “ “ “ “
“ 2 “ “ 0.40–0.43 “ “ “ “
“ 3 “ “ 0.44–0.52 “ “ “ “
“ 4 “ “ 0.53–0.60 “ “ “ “
“ 5 “ “ 0.61–0.70 “ “ “ “
“ 6 “ “ 0.71–1.16 “ “ “ “
“ 7 “ “ 1.17–1.80 “ “ “ “
“ 8 “ “ 1.81–3.15 “ “ “ “

The ash insoluble in hydrochloric acid is known as sand.

4. **MICROSCOPY OF FLOUR.**—The most important means of determining the identity and purity of flour is microscopic examination. As a simple preliminary measure, the flour should be examined with reference to the coherence of the gluten (p. 340) by the so-called **Bamihl Test.**[2] This consists in mounting a small portion in water and rubbing back and forth with a cover glass. Wheat flour, even when present to the extent of 10 per cent in rye flour, yields gluten strings, but rye flour yields practically none. Strings may also be observed in maize flour, but these are very small. Bakers have made the test since time immemorial by rubbing a small portion of flour on the tongue.

---

[1] Untersuchung von Mehlsorten nebst einer neuen Methode zur Bestimmung der Feinheit der Mehle. Ztschr. Angew. Chem. 1893, **23**, 691.

[2] The history of this simple test should here be related since it shows the necessity for caution in accepting “new” discoveries. The late Prof. TOMASCHEK of Brünn described the test in 1882 and abstracts were published in various journals (e.g. Ztschr. allg. Österr. Apoth. Ver. 1882, No. 24). In 1892 it was again brought to notice as a new method by KLEEBERG (Chem. Ztg. 1892, 1036). The author, in a communication to the Chemiker Zeitung (1892, 1185), referred to TOMASCHEK as the discoverer of the test, but was informed by TH. KYLL (Chem. Ztg. 1892, 1257) that the customs officer BAMIHL had devised it in 1852 (Pogg. Ann. 1852, 161) and had introduced it into the Prussian custom houses, where it has ever since been in use. WINTON uses 0.02 per cent eosin solution, the dye being greedily absorbed by the gluten strings, thus rendering them distinct to the naked eye.

The so-called **Chloroform Test** in many cases is well adapted for quickly determining whether a given sample is, or contains, rye flour. About 10 grams of flour are placed in a test tube and sufficient chloroform is added to fill the tube to twice the height of the flour. After some hours, by far the greater part of the flour will be found floating as a compact mass, while beneath this the chloroform is evident as a layer of a somewhat yellower color. At the bottom of the test tube is a deposit consisting of mineral matter and isolated tissue elements, chiefly fragments of the aleurone layer with the cell contents. If the mineral matter is considerable, it is probable that sand or some other inorganic material has been added. The color of the so-called aleurone grains furnishes valuable information as to the presence of rye flour. The aleurone grains of rye are bluish, blue, or green, and the deposit is strikingly blue or blue-green, while the same elements of wheat are yellow or brownish gray. FR. BENECKE[1] has systematically developed this method of investigation and concludes that the fineness of the flour can be determined by the number of the aleurone cells since the larger part of the deposit consists of these.

The microscopic examination should begin with a very thorough study of the starch grains. Most of the necessary details are given in the chapter on starch (see pages 27 to 49). The distinction between wheat and rye starch in mixtures is somewhat uncertain—at least if the temperature of gelatination is not considered. On the other hand, it is very easy to recognize maize flour by the characteristic polyhedral starch grains, which are, for the most part, in larger or smaller masses.

Many samples of flour contain occasional, less often numerous, club-shaped, spindle-shaped, sausage-shaped, or flask-shaped starch aggregates made up of minute grains. These are derived from the endosperm of the seeds of cockle (*Agrostemma Githago* L.), and it should here be stated that it is a remarkable fact that none, or only traces, of the spermoderm of cockle occurs as an impurity of flour containing the starchy matter of this seed. This is due to the modern process of milling, which accumulates the floury portion of the seed in the fine flour and the harder constituents, including the hulls, in the last grindings. From this it is evident that the hulls occur in considerable amount in the higher numbers of the flour.

---

[1] Landw. Vers. Stat. 1889, **36**, 337. The author is able to confirm the results of Benecke's investigation throughout and considers this method a very serviceable one for the detection of rye flour in wheat flour; it requires, however, some experience and considerable expenditure of time.

The fragments of the tissues present in the flour must be separated in a suitable manner for examination. A portion of the material is flattened and smoothed on the surface and all the brown or dark-colored particles are picked out with the aid of a lens. If these belong to the bran coats of wheat, they may be easily recognized by their histological elements, of which the hairs, the mesocarp, the cross-cells, the spermoderm, and the aleurone layer are most easily recognized.

Schimper's Foam Test, or successive boiling with dilute acid and alkali, may be used for accumulating the tissues from a considerable amount of flour for microscopic examination. The former method consists in boiling, with stirring, a portion of the flour in a large amount of water. Various tissue elements, notably the hairs, accumulate in the foam which forms on the surface. The second method [1] consists in boiling first with dilute hydrochloric acid, thus converting the starch into soluble carbohydrates and then, after decanting off the solution, with dilute sodium hydrate.

A. VOGL recommends treatment with **Alcoholic Naphthylene Blue** (0.1 g. naphthylene blue; 100 cc. absolute alcohol; 400 cc. water) as follows: "A small portion of the flour (about 2 grams) is intimately mixed on a watch glass with alcoholic naphthylene-blue solution. After standing for a time a portion is spread uniformly on a slide, either with a rod, or, better, with a camel's-hair brush, allowed to dry, mounted in a drop of sassafras oil, or some analogous essential oil, or else in creosote, guaiacol, and finally examined microscopically. If bubbles appear in the mount, these may be removed by gently warming the slide. By the treatment described every particle from the bran coats or chaff is rendered beautifully distinct. The cell membranes of the epicarp, the mesocarp, the cross-cells, the hairs, and the glumes, also the contents of the aleurone cells and the cells of the embryo, are colored by the naphthylene blue a beautiful blue or blue-violet and the cell walls of the aleurone cells pale blue, while the membranes of the starch cells, also the starch grains, remain colorless and are rendered so transparent by the essential oil, creosote, guaiacol, etc., that only the colored particles are distinctly evident." [2]

As regards the contamination of flour with weed seeds (or weed fruits), fungi, and fungous spores it should be stated that these are treated in the special works on the microscopy of foods. In this work they can only be briefly mentioned. The most common impurities are fruits of black bindweed (*Polygonum Convolvulus* L.), the seeds of cockle (*Agrostemma Githago* L.), various leguminous seeds known collectively as tares, also fruits of bedstraws (*Galium*), cow wheat (*Melampyrum arvense* L.), *Alectorolophus hirsutus* Allion, *Atriplex*, darnel (*Lolium temulentum* L.),[1] finally smut spores, and ergot (chiefly in rye flour).

---

[1] KÖNIG: *loc. cit.* WINTON: Microscopy of Vegetable Foods. New York, 1915, 54.

[2] VOGL: Die wichtigsten vegetabilischen Nahrungs- und Genussmittel, 17.

The **Alcohol-Hydrochloric Acid Test**, also devised by A. VOGL,[2] is valuable in the preliminary examination. "Two grams of the flour are shaken violently in a test tube with about 10 cc. of 70 per cent alcohol containing 5 per cent of hydrochloric acid, finally warmed, allowed to settle, and the color of both the deposited flour and the supernatant liquid at the meniscus observed by reflected light." Pure wheat flour remains white, the liquid colorless; ergot imparts to both the flour and the liquid a flesh color with a blood-red meniscus, cow wheat and *Alectorolophus hirsutus* a blue-green, and legumes a rose-red to light violet color.

Having studied the wheat kernel, we will now turn our attention to a chaffy cereal for the purpose of learning the structure of the chaff which is often present, in a more or less finely ground condition, in many feeds and raw materials used in the arts.

BARLEY. CHAFF OF RICE AND MILLET.

The fruits of common or four-rowed barley (*Hordeum sativum* var. *vulgare* (L.) Hackel = *H. vulgare* L. = *H. tetrastichum* Kcke.) and two-rowed or malt barley (*Hordeum sativum* var. *distichon* (L.) Hackel = *H. distichum* L.) are the most common varieties of this cereal; the former serves for the production of hulled or rolled barley, barley flour, fodders, etc., while the latter is the only variety used for the manufacture of malt. Because of the numerous products, a knowledge of the anatomical structure of the barley grain, and especially of the chaff, is of importance to the technical microscopist.

The grains of most varieties of barley are chaffy, that is the two floral parts, known as the flowering glume and palet, are so closely adherent to the fruits that they may be said to be grown to it. That they are not actually grown to the fruit may be demonstrated by soaking the grain for some hours in water, after which they may be readily separated. The chaffy grain is upward of 1 cm. long, elongated spindle-shaped, narrowed toward both ends. In the broadest part, which is in the middle or a little below, it is 3–4 mm. broad. On the dorsal side the grain is almost flat, wrinkled, with one middle and two side ribs; on the rounded ventral side there is a longitudinal groove. On the two narrow sides the edges of the flowering glume overlap the palet. Freed from these envelopes the grain is pointed or blunt at the base and is wrinkled on the surface.

---

[1] In darnel a fungus, first noted by VOGL, is almost always found between the perisperm and the aleurone layer.

[2] VOGL: Die gegenwärtig am häufigsten vorkommenden Verfälschungen, etc., der Mehle. Wien, 1880.

In addition to the chaffy barleys there are also naked varieties, the fruits of which fall out of the chaff during threshing.

CHAFF.—The anatomical structure of the two envelopes is in most details the same, but the palet is somewhat the thinner. In both we find an outer epidermis, a fiber layer, a spongy parenchyma layer, and an inner epidermis, arranged in the order named.

The most characteristic tissue is the **Outer Epidermis** (Fig. 208, *1*). This consists of the so-called long cells (*ep*) and short cells (*k*, *s*). As seen in cross-section, the long cells are rectangular, with thickened outer walls; in surface view they are elongated, narrow, richly pitted elements, which, like the other cells, are strongly silicified. If a piece of the epidermis is burned to an ash, the elongated wavy walls are very distinct. Between the long cells at the ends are the short cells. They occur either singly ("silica cells"), in which case they have a rounded lumen and not infrequently are extended beyond the surface in the form of very short, blunt, conical, strongly sclerenchymatized trichomes (*k*), or else in pairs (*s*), one of the cells being larger, usually crescent-shaped, clasping the other cell. The pairs of cells ("twin cells") have the appearance of being abortive stomata. Here and there, according to A. Vogl, only one of the twin cells is developed. Toward the edges the cell walls are thinner and more delicate, and the undulations are less pronounced.

Epidermal cells, isolated by boiling in potash solution, show on the long sides the wavy outline with projections which fit into the corresponding bays of neighboring cells. These cells, which we have already observed in our study of straw pulp (see Fig. 85, *e*), together with the annular vessels are the characteristic elements of the grasses.

The tissue immediately beneath the epidermis, known as the **Hypoderm**, consists of pitted and strongly thickened mechanical elements with the character of bast fibers (Fig. 208, *2*). **Spongy Parenchyma** (*3*), several cells thick, forms the next layer. The intercellular spaces are for the most part small and frequently are replaced by peculiar folds of the appearance according as the knife passed through the projections or bays of the side walls. The radial walls (those perpendicular to the surface of the chaff) are also sinuous.

Powdered rice chaff, or hulls, a well-known adulterant of spices and cattle foods, may be identified by the epidermal cells.[1]

Millet Chaff (Fig. 209, 2).—The outer epidermis of the chaff of common millet[2] (*Panicum miliaceum* L.) and of German millet (*Setaria italica* Jessen) resembles somewhat that of barley, but there are no short cells or twin cells. The longitudinal walls are uniformly and very deeply

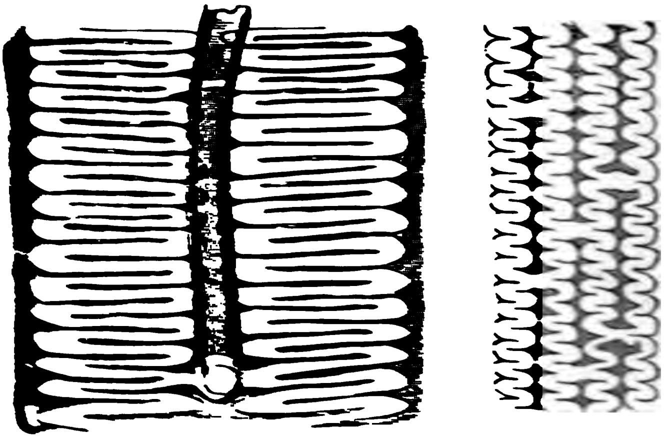


Fig. 209.—Outer Epidermis of Chaff in Surface View. 1, Rice; 2, Millet. ×400. (T. F. Hanausek.)

sinuous.[3] After solution by maceration the inner walls of the epidermal cells and the outer walls of the adjoining hypoderm cells show pointed or [illegible] resembling saw teeth. These, according to v. Höhnel,[4] [illegible] the projections of one [illegible] correspond- [illegible]

---

[1] [illegible] surface striations [illegible] is [illegible]

[2] [illegible] 1. [illegible] 42-46. [illegible] of German millet [illegible]

[3] [illegible]

[4] [illegible] der Epidermis. Haber- [illegible] und Ver- [illegible] und der Bereitung [illegible]

Ground millet chaff has long been used in Europe as an adulterant of spices.

Fruit.—We will now return to barley. Having learned the structure of the chaff we will next study the tissues of the fruit.[1] The general structure of the pericarp, spermoderm, perisperm, endosperm, and embryo is much the same as that of wheat, which has already been described. This latter cereal, however, on ripening separates from the chaff and the bran coats alone serve to envelop the inner tissues. Since, in the case of barley, this protective function is exercised largely by the chaff, the bran coats are not strongly developed, as may be seen after softening the grain in water and carefully removing the chaff.

The fruit thus separated from the chaffy envelopes is enclosed by a thin yellow-red skin in which may be distinguished an epicarp, an indistinct mesocarp, a double cross cell layer, and a spermoderm. We find then in barley the same tissues, although somewhat modified, that we observed in our study of wheat.

The **Epicarp**, as seen in surface view, consists of somewhat irregularly polygonal, or rounded polygonal, cells with hairs and stomata. The thin-walled hairs at the basal end are strikingly broad and sometimes pitted and, for the most part, elongated and pointed at the apex.

The **Mesocarp** is made up of very indistinct compressed cells, while the next layer consists of a double row of thin-walled but distinct **Cross-cells**. Rather numerous intercellular spaces of various sizes give this layer in parts the characters of a spongy parenchyma. Here and there the cells are square, arranged in longitudinal rows.

Thin-walled **Tube Cells** occur here and there beneath the cross-cells.

In cross-section the **Spermoderm** appears as a brown streak made up of an outer thin-walled layer and an inner layer with thickened walls.

Next follows the **Perisperm**, or **Hyaline Layer**, and after that the **Aleurone Layer**, which usually is three cells thick. This triple layer is of great value in diagnosis since in other common cereals only one cell layer is present.

The **Starch Cells** of the endosperm may also be distinguished from those of wheat and rye, owing to the swelling of their walls in water, a character which may be easily noted in barley flour. Barley starch is described on p. 38.

---

[1] See Vogl: Die wicht. Nahrungs- und Genussmittel, 92.

We are now in a position to detect microscopically the elements of barley fruit and its mill products.

BARLEY COFFEE; MALT COFFEE.

Sometimes samples of so-called barley coffee are submitted for examination to determine whether the material consists of roasted barley or roasted malt. Although oftentimes the tissues are so altered by the roasting that their identification is scarcely possible, as a rule the question is easily answered.[1]

Malt is the sprouted grain which at a certain stage has been kiln dried to arrest further growth. A longitudinal section of the barley grain shows the embryo at the base and the starchy endosperm making up the bulk of the grain. If, however, the kernel has sprouted, i.e., if the radicle of the embryo has grown in length and pushed itself out of the kernel and the plumule on the opposite end has developed upwards, the newly formed tissues, because of the delicacy of their cell walls and their succulence, are much more easily destroyed than those of the unsprouted grain. A portion of the starchy matter has also been used up in the formation of new tissues. If the sprouted grain is roasted to a deep brown color, as is done in preparing coffee substitutes, the delicate portion of the germ still remaining in the grain is charred and almost completely destroyed, while in the [illegible] the embryo is a [illegible] of the starchy [illegible] If the grain is [illegible] malt sprouts, [illegible]

[illegible]

[illegible]

---

[1] [illegible]

[illegible]

separated in like manner from the chaff. The removal of the fragments of the envelopes from No. 3 is accomplished with the aid of v. WEINZIERL's lens, but in the case of Nos. 1 and 2 the naked eye suffices.

The portions thus separated are weighed and the percentages calculated.

The following operation was specially designed for separating millet flour and millet chaff, but may also be used *mutatis mutandis* for other materials.

4. OPTICAL SEPARATION OF MILLET FLOUR AND VERY SMALL FRAGMENTS OF MILLET CHAFF.—

(*a*) *Separation and Quantitative Determination of Millet Flour.* After some practice it is possible to prepare microscopic mounts of portion No. 4, which can not further be separated mechanically into its constituents, in such a manner that the field is uniformly filled with the flour particles.

The contours of the millet starch grains, or groups of grains, in the field are then sketched with the aid of a camera lucida. In order to secure reliable results it is necessary to prepare at least 5–10 mounts and examine about three fields of each.

After having determined once for all the size of the field with a given magnification, it is necessary merely to determine the surface covered by the millet starch, which is accomplished with the aid of Amsler's polarplanimeter, a reliable instrument much used by engineers in determining the area of irregular figures.

An average is taken of the figures obtained in the individual examinations, rejecting extremes, and the fraction of the whole field covered by the starch calculated. The desired percentage of millet flour is obtained by multiplying the percentage of No. 4 in the whole product by the fraction thus found, disregarding the specific gravity and the thickness of the individual constituents of the flour.

(*b*) *Separation and Quantitative Determination of the Millet Chaff in the Flour* (portion No. 4). For the determination of the amount of minute fragments of fruit envelopes (glumes and paleæ) in the fourth portion, mounts are prepared as described under (*a*) and the average area of the fragments in a field determined with the polarplanimeter.

Since millet chaff has a lower specific gravity than the other constituents of the flour, it is necessary to take this specific gravity into consideration in determining the percentage by weight, thus avoiding what, under some conditions, would be a considerable source of error. The following formula is calculated from the well-known relation between the specific gravity and absolute weight of a body and its volume:

$$G_h = G_4 \cdot \frac{F_h}{F_k} \cdot \frac{S_h}{S_4},$$

in which G_h is the desired percentage by weight of millet chaff (glumes and palets) in No. 4, G_4 the percentage by weight of No. 4 in the original material, F_h the area of millet chaff, F_k the area of the whole field, S_h the specific gravity of millet chaff, S_4 the specific gravity of No. 4.

The specific gravity of millet chaff is 1.224; that of No. 4 must be determined in each case.

The following analyses, selected from those given by v. WEINZIERL in his original paper, illustrate the practicability of this admirable method.

MECHANICO-MICROSCOPICAL ANALYSES OF GENUINE AND FALSE BARLEY GROATS.

Diameter of Particles.	Barley Groats No. 1. Genuine.		Barley Groats No. 2. By-product from Pearl Barley.	
	Per Cent by Weight.	Constituents.	Per Cent by Weight.	Constituents.
Larger than 1.5 mm...	0.05	0.05% barley chaff	31.20	14.0% chaff 17.2 endosperm and fragments of pearl barley.
Larger than 0.5 mm...	18.00	4.3% chaff 4.5 endosperm 9.2 embryo	41.10	6.0% chaff 35.1 endosperm
Larger than 0.25 mm..	15.20	1.7% chaff 6.9 endosperm 6.6 embryo	12.50	4.0% chaff 8.5 endosperm
Smaller than 0.25 mm	66.75	66.75% barley flour	15.20	15.2% barley flour
Total..........	100.00		100.00	

Summary of No. 1:	
Chaff.......	6.05%
Endosperm..	11.40
Embryo.....	15.80
Flour.......	66.75
	100.00

Summary of No. 2:	
Chaff......	24.00%
Endosperm..	60.80
Flour.......	15.20
	100.00

These two samples show a striking difference in quality. It is obviously unfair to market the by-product from the manufacture of pearl barley under the name of barley groats, since it contains much more chaff and much less flour than the genuine product.

The following example illustrates the applicability and accuracy of the method in determining the percentage of an admixture. A sample of barley groats adulterated with 10 per cent of millet bran gave on analysis a little over 8 per cent of the latter, the error being upward of 2 per cent.

MECHANICO-MICROSCOPICAL ANALYSIS OF BARLEY GROATS CONTAINING 10% OF MILLET BRAN.

Diameter of Particles.	Per Cent by Weight.	Constituents.
Larger than 1.5 mm.	0.15	0.13% barley chaff 0.02 millet chaff
Larger than 0.5 mm.	17.78	5.70% barley chaff 11.00 barley endosperm 1.08 millet chaff
Larger than 0.25 mm.	30.75	3.55% barley chaff 20.20 barley endosperm 7.00 millet chaff
Smaller than 0.25 mm.	51.32	51.32% barley meal
Total.	100.00	

Summary: Barley groats.................... 91.90%
Millet bran...................... 8.10

Oil Cakes.[1]

Oil cakes are the residues left after removing the oil from seeds or fruits whether by pressure or by solvents. Of late years they have become of great importance in agriculture and animal production, being used to some extent as fertilizers and very extensively as concentrated cattle foods. The high content of protein and, notwithstanding the extraction, the considerable amount of fat, as well as the easy digestibility, render them especially valuable for feeding farm animals.

Oftentimes the technical microscopist is called on to report as to the identity or purity of oil cakes, as these products frequently suffer substitution and adulteration. He may also have occasion to express an opinion, based on his microscopic examination, as to the value or adaptability of certain products, thus corroborating or supplementing the results of the chemical analysis. By comparison with mixtures of known percentage composition he may estimate the amount of the several constituents in an unknown mixture and, from the amount of woody indigestible constituents, nitrogenous substances, or of very fatty elements, etc., draw a conclusion as to the feeding value of the product. Such work naturally calls for much practice and experience, and especially an accurate knowledge of the anatomical structure of the various oil fruits and oil seeds. Since space is here lacking for an exhaustive description of all these raw materials,[1] only a few are considered in detail, while the remainder are treated briefly, noting the elements of chief value in diagnosis.

---

[1] T. F. HANAUSEK: Realenzyklopädie d. ges. Pharm. 2. Aufl., **9**, 465.

PROCESSES OF MANUFACTURE.—The oil fruits or oil seeds are usually crushed in stamps or between rollers and afterwards ground more or less finely in mills of special construction. The oil is obtained from the ground material either by pressure or by extraction with benzine or other solvents. Fine table oils are obtained by cold pressure, but the residue from this process contains a considerable amount of oil which is removed by pressure at a higher temperature (50–100° C.). After the first pressing, the material is reground with the addition of water, thus permitting the removal of the larger part of the fat by a second pressing. Notwithstanding this treatment, BENECKE finds that the cake, which must be dried for several weeks after removal from the press, still contains 5–10 per cent of oil. Processes depending on the extraction of the oil with carbon bisulphide, or more commonly benzine, are much more efficient and yield residues in the same powdered condition as before the extraction.[2]

The residues after removal of the oil belong in three classes: (1) *True Oil Cakes*, or the residues after expressing the oil; (2) *Oil-seed Meals*, or the residues after extracting the fat with solvents; (3) *Oil-cake Meals*, or ground oil cakes. BENECKE states that the latter are often again brought into a compact form by pressing, frequently with addition of worthless, or even injurious, materials.

METHODS OF EXAMINATION.—A complete examination of an oil cake involves (1) chemical, (2) practical (physiological), and (3) microscopical tests. Chemical analysis serves in the determination of the percentages of water, ash, protein (nitrogen×6.25), crude fiber, fat, etc. Practical trials are for the purpose of determining the nutritive value and the digestibility when fed to cattle for fattening, also the effect on milk production, etc. If, however, it is desired to ascertain the origin or purity of a cake, or to value approximately the fatty or nitrogenous substances contained in it, recourse must be had to microscopic examination.

---

[1] The most important are described by the author in Wiesner's Die Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903, **2**. See also BENECKE: Anleitung zur mikroskop. Untersuchung der Kraftfuttermittel. Berlin, 1886. *Idem:* Die Bedeutung der mikroskop. Untersuchung, etc. Dresden, 1888. BÖHMER: Die Kraftfuttermittel. Berlin, 1903. COLLIN et PERROT: Les Résidus Industriels. Paris, 1904. KÖNIG: Untersuchung landwirthschaftlich und gewerblich wichtiger Stoffe. Berlin, 3. Aufl. 1906, 331. MOELLER: Mikroskopie der Nahrungs- und Genussmittel. Berlin, 2. Aufl. 1905. WINTON: Microscopy of Vegetable Foods. New York, 1915.

[2] Linseed oil is obtained in four ways: (1) in stamp mills, (2) in hydraulic presses by the French system, (3) in American or Anglo-American presses, and (4) by extraction with benzine.

Sampling.—Samples of oil-cake meals may be readily obtained by mixing portions taken from different places in the lot. Oil cakes, which are ordinarily in large hard plates, may be sawed in two directions and the sawdust thus obtained mixed.

Preliminary Test.—First of all tests are made with iodine for starch. Most of the oil cakes, peanut cake excepted, contain no starch or only traces, so that the presence of this substance in appreciable amount at once suggests that the material is adulterated with a cereal flour or some other starchy substance. In such cases an attempt should be made to identify the source of the starch.

A portion of the sample is next placed in a test tube with chloroform, violently shaken, and allowed to settle as in the examination of flour. Two layers are thus formed: (1) an upper floating layer consisting of most of the organic elements, and (2) a deposit which sometimes, but not always, contains fragments of shells and often consists largely of sand and other mineral matter. If a considerable amount of sand, clay, chalk, etc., is present, it is reasonable to conclude that the product contains an adulterant the exact nature of which is determined by chemical analysis.

Microscopical Examination is made as directed for flour (p. 346). It is often desirable to separate the material by sifting[1] into portions of different fineness and examine each portion separately, first in water, then in alkali, alcohol, etc. Another procedure is to treat the material first with caustic-soda solution, then with glycerine-acetic acid; this treatment usually brings out the different elements with remarkable distinctness. Large hard particles are softened in potash and crushed on a slide. If they are of sufficient size they may be held between pieces of cork or embedded in glycerine gum and sectioned with a razor. Since a considerable amount of fat or oil makes the mount cloudy, thus obscuring the other elements, it is recommended to lay the material in chloroform, ether, benzol, or some other fat solvent, or else to clear by soaking for some hours in chloral hydrate. Most of the oil cakes have such characteristic tissue elements as to permit their identification. Some of the weed seeds, especially those of the *Cruciferæ*, are more difficult or impossible to identify.

---

[1] See Weinzierls' method, p. 354.

COTTONSEED CAKE AND COTTONSEED MEAL.[1]

Cottonseed cake and the ground cake, commonly known as cottonseed meal, are now used in enormous quantities for feeding cattle. American cake and meal are made largely from the seed of common or upland cotton (*Gossypium herbaceum* L.). Until recently the seed, after ginning, was decorticated and the meal contained but a small amount of hulls although often contaminated with cotton fiber and sometimes with bits of iron. For years the hulls were used as fuel in the oil mills and the ashes, at first thought to be worthless, were later found to be valuable as a source of potash for tobacco culture. In recent years cotton hulls have come into extensive use as a cattle food. At the present time it is the common practice in the United States to express the oil from the undecorticated seed and consequently the meal and cake contain a much greater amount of hulls than formerly and are not so rich in protein.

The seeds of Sea Island and Egyptian cotton, both varieties of *G. barbadense* L., can not be readily decorticated and the cake and meal from these varieties always contain the full amount of hulls, although, owing to the ease and completeness with which the fibers are separated from the seed by ginning, these products seldom are contaminated with appreciable amounts of lint. Egyptian cottonseed cake is extensively used in England. According to VOELCKER,[2] the inferior cake from Bombay seed is often substituted. The frequent cases of poisoning resulting from the use of cottonseed meal have not been satisfactorily explained. Some have attributed the cause to the presence of impurities or the abnormal growth of fungi. KÖNIG states that it has not yet been decided whether a poisonous substance similar to the alkaloids of lupines is present or whether putrefactive bases are formed as a result of improper storage.

---

[1] The manufacture, composition, etc., are treated in the following: GEBEK: Ueber Baumwollsaatmehl und Baumwollsamenkuchen. Landw. Vers. Stat. 1893, **42**, 279–309. The description of the microscopic characters given in the last is based almost entirely on the author's article (Ztschr allg. Österr. Apoth. Ver. 1888, **26**, 569, 591). LAMBORN: Cottonseed Products. New York, 1904.

[2] Method of Discriminating between Egyptian and Bombay Cottonseed Cake. Analyst, 1903. **28**, 261.

Cottonseed products are easily identified and tested as to their purity by microscopical examination; it is also very easy to distinguish the decorticated from the undecorticated product. American cottonseed meal is usually strikingly yellow. Gebek[1] attributes a brown color to overheating during pressing, or to old seeds, also possibly to spontaneous heating. He further states that the Egyptian cake is yellow with dark particles of hulls and, in the fresh condition, with a tinge of green.

MICROSCOPIC STRUCTURE.

The seed consists of an outer shell (spermoderm), a thin skin (perisperm and endosperm), and the embryo with two much-folded cotyledons. The brown **Spermoderm** is made up of six layers, the arrangement of which is evident in cross-section (Fig. 210).

The **Epidermis** (Figs. 210 and 211, *a*) is composed of rather large cells with thick, distinctly laminated, yellowish walls and brown contents, also of cells elongated so as to form hairs (*h*). On seeds with a ground wool the thickened cells are largely the basal portions of cotton hairs, but on those without ground wool it may be seen that a circle of free cells surrounds each hair cell (Fig. 211, *a*). These epidermal cells with their deep-brown contents are highly characteristic of cotton hulls.

Beneath the epidermis lies the **Outer Brown Layer** (Figs. 210, 211, *b*) consisting of several layers of thin-walled, opaque, tangentially compressed cells impregnated with a brown coloring substance, also of well-developed vascular bundles. In surface preparations these brown cells are usually found attached to the third layer, which they color brown.

The third layer, known as the **Colorless** or **Crystal Layer** (Figs. 210 and 211, *c*), is one, two, or rarely three cells thick. These cells are polyhedral in surface view and quadrilateral in cross-section, with thick, colorless, lignified walls. Contained in these cells are single oxalate crystals or granular masses.

---

[1] *Loc cit.*, 283.

[2] Böhmer: Kraftfuttermittel. Berlin, 1903, 336. v. Bretfeld: Anatomie der Baumwolle- und Kapoksamen Jour. Landw. 1887, **35**, 29–56. Collin et Perrot: Les résidus industriels. Paris, 1904, 178 T. F. Hanausek: Zur mikroskopischen Characteristik der Baumwollsamenprodukte. Ztschr. allg. Österr. Apoth. Ver. 1888, **26**, 569, 591. *Idem:* (Oelkuchen) Realenzyklopädie d. ges. Pharm. 2. Aufl. 1907, **9**, 467. *Idem:* Wiesner's Die Rohstoffe des Pflanzenreiches. 2. Aufl. 1903, **2**, 754. Kobus: Kraftfutter und seine Fälschung. Landw. Jahrb. 1884, **13**. Winton: The Microscopic Examination of American Cottonseed Cake. Analyst, 1904, **29**, 44. *Idem:* The Anatomy of Certain Oil Seeds with Especial Reference to the Microscopic Examination of Cattle Foods. Conn. Agr. Exp. Sta. Rpt. 1903, 175. *Idem:* Microscopy of Vegetable Foods. New York, 1915, 207.

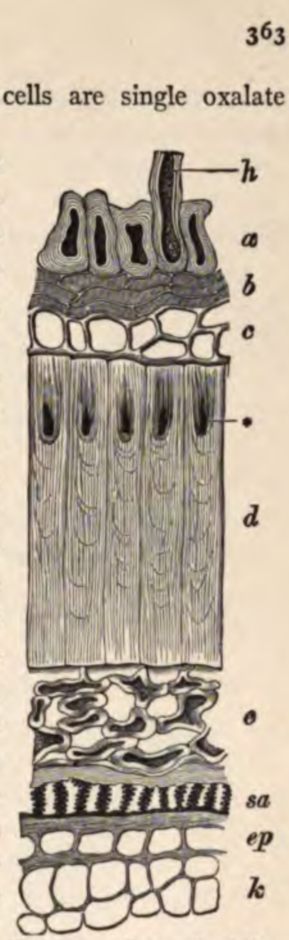


FIG. 210. Cotton Seed (*Gossypium herbaceum*). Cross-section of Hull. (T. F. HANAUSEK).

Spermoderm consists of *a* outer epidermis with *h* hair, *b* outer pigment layer (crystal layer), *d* palisade cells with lumen at *, *e* inner brown layer (the large intercellular spaces are present only in certain parts of the spermoderm) within which is an inner layer of obliterated cells; *sa* fringe cells of perisperm; *ep* endosperm; *k* cells of cotyledon.

The fourth layer, consisting of **Palisade Cells** (Fig. 210, *d*), furnishes mechanical protection to the seed. A very similar layer occurs in seeds of *Bombaceæ* (see kapok cake, p. 368). It is composed of enormously long, radially arranged, narrow, prismatic, partially sclerenchymatized cells. In cross-section the casual observer might conclude that this layer was made up of two cell layers. This apparent division is due to the fact that the outer portion of each cell has a distinct lumen filled with brownish-yellow contents, which broadens into a rounded cavity at about one-third the distance between the outer and the inner ends (Fig. **210**, *d**). It is also remarkable that in the outer portion the cell wall is not lignified and is colored blue with chlorzinc iodine, while in the middle portion the walls give a strong lignin reaction with phloroglucin-hydrochloric acid. This last reagent colors the basal part of the palisade cells a brownish-yellow color, due perhaps to the pigment of the next layer, although the same color is obtained with isolated palisade cells.

The palisade cells are also characterized by their cross-sections, which are seen in tangential sections of the seed, cut at different depths from the surface. At the outer ends, where the cells are somewhat rounded, the lumen is star-shaped with narrow pointed rays; in the part where the lumen is largest the rays are broad, while the walls form tooth-like projections into the lumen; in the inner lignified portion the lumen is reduced to a mere point from which radiate delicate lines.[1]

Next follows the fifth or **Inner Brown Layer**, which like the outer

---

[1] The deportment of these cells toward polarized light is treated by v BRETFELD: Anatomie der Baumwoll- und Kapoksamen. Jour. Landw. 1887, **35**, 29–56.

[illegible]

[illegible] different stages [illegible] [illegible] are hyphae-like. [illegible] excess of alcohol is removed and chlorzinc iodine added. By this process the fat is largely removed, also the aleurone grains, excepting the crystalloids, which for a time remain as minute angular granules, but finally disappear. The sections are now suitably cleared and each cell appears very distinct. No blue coloration forms with the chlorzinc iodine. Beneath the inner side of each cotyledon,—the side where the two cotyledons are in contact, the upper side after unfolding—is a layer of palisade cells and beneath this last still another layer of shorter cells. The remainder of the mesophyl consists of rounded cells with intercellular spaces. On many of these latter cells are small round or oval rings which presumably are short projections indicating that this tissue is an embryonic spongy parenchyma.

The contents of the mesophyl cells are oily protoplasm and aleurone grains, both of which are removed by the above treatment, here and there crystal rosettes of calcium oxalate, and small lumps of starch.

Distributed among the mesophyl cells are procambium bundles (Fig. 213, *prc*) and globular, lysigenous **Secretion Cavities** (*se*) 100–400μ in diameter. The latter are known by some authors as resin glands. The lysigenous character[1] of these cavities when mature is quite clearly evident. The tissue which surrounds them consists, in its outer portion, of tangentially flattened, very thin-walled cells, and within the last a mucilaginized layer in which traces of the cell walls are still evident. This colorless mucilage layer, which treatment with hydrochloric acid and, after washing with water, with potash brings out as a yellow, folded, and laminated mass, encloses the greenish-black, opaque secretion (*v*). Since the mucilage layer is soluble in water, the secretion flows out from sections laid in water in the form of a thick emulsion consisting of a colorless mass containing minute dark-colored grains (resin?) in lively molecular motion. Chlorzinc iodine colors the secretion red-brown, sulphuric acid dissolves it to a thick turbid fluid of a blood-red color. Ammonia colors the liquid greenish yellow without destroying the emulsion. Potash also imparts a green color.

The **Radicle** consists of rounded cells containing a considerable amount of small grains of starch.

In decorticated cottonseed cake and meal we find the extraordinarily thin-walled cells of the cotyledons containing oil, aleurone grains, crystal clusters of calcium oxalate, also the characteristic fringe cells, and the strikingly large, globular, greenish black, entirely opaque secretion masses becoming blood-red in concentrated sulphuric acid. Undecorticated cake and meal, also to some extent the decorticated products, contain, in addition to the elements named, the highly characteristic palisade cells, the thick-walled epidermal cells with brown contents, cotton fibers, and fragments of the two brown layers. Adhering to the fragments of the outer brown layer are often cells of the colorless layer. The large secretion cavities are evident as black specks even to the naked eye.

---

[1] v. HÖHNEL speaks of these "glands" as being lysigenous. See his Anatomische Untersuchungen über einige Secretionsorgane der Pflanzen. Sitzb. Akad. Wiss. Wien. 1881, I, 84, 566, 578.

KAPOK CAKE.

Various trees of the family *Bombaceæ* yield fruits with a thick felt on their inner walls, the hairs of which we have already learned (p. 68) under the name of vegetable down. The seeds themselves are free from hairs, but are very rich in oil and protein (62.1 per cent of fat and 22.65 per cent of protein) and are therefore well adapted for the production of oil and cake. At the present time two kinds of kapok cake are on the market, as follows:

1. **JAVA KAPOK CAKE** is obtained from the seeds of the kapok or silk cotton tree (*Ceiba pentandra* Gärtn =*Eriodendron anfractuosum* DC.=*Bombax pentandrum* L., Wollbaum, fromager, Donsboom, Panja-, Sangori-, Algodansbaum). The tree grows in Mexico, the Antilles, Guiana, Africa, also throughout the East Indies and the Malay Archipelago.[1]

2. **EAST INDIAN KAPOK CAKE** is from the seeds of various species of *Bombax*, especially *Bombax Ceiba* L. (=*B. Malabaricum* DC.=*Salmalia Malabarica* Sch. and Endl.=*Gossampinos rubra* Hook.) which occurs in the regions between Hindustan and West Australia. Only the latter is considered in the brief description which follows:

MICROSCOPIC STRUCTURE.[2]

The seed is in general structure the same as cottonseed and the cake contains microscopic elements similar to those of cottonseed cake, but sufficiently different to permit ready distinction from the latter.

Thick-walled **Epidermal Cells** and epidermal hairs, which are so characteristic of cottonseed, are replaced in kapok seed by elements of quite different structure, and the same is true of the **Outer Brown Layer.** The tissues are dark brown with roundish polyhedral, richly and coarsely pitted cells which here and there are sclerenchymatized. The **Crystal Layer** is several cells thick and the cell walls are pitted, almost collenchymatously thickened, and the crystals of calcium oxalate occur only in large clusters, not in single crystals. **Palisade Cells** of the same structure occur in both cotton and kapok seeds, but in the latter they are one-third shorter than in the former. The **Fringe Cells** of the **Perisperm** have much simpler threads and often have yellow contents. The tissues of the **Embryo** are closely packed with oily protoplasm and aleurone grains; crystals and secretion cavities, such as occur in cottonseed, are completely lacking. The absence of thick-walled epidermal cells and of secretion cavities, the presence of a crystal layer several cells thick, and of a palisade layer one-third shorter than in cottonseed, serve for distinguishing kapok from cottonseed cake.

---

[1] SCHUMANN in ENGLER-PRANTL: Pflanzenfamilien, III, **6**, 63.

[2] BRETFELD: Anatomie der Baumwoll- und Kapoksamen. Jour. Landw. 1887, **35**, 29. T. F. HANAUSEK: Realenzyklopädie d. ges. Pharm. 2. Aufl. 1907, **9**, 472. KOBUS:

Java kapok cake contains similar microscopic elements.[1]

PUMPKIN-SEED CAKE.

The high percentage of protein (29–55.6 per cent) in pumpkin-seed cake [2] gives this product a high feeding value, although unfortunately comparatively small amounts are available.[3] Seeds of both the true pumpkin (*Cucurbita Pepo* L.) and the squash (*C. maxima* Duch. and *C. moschata* Duch.) are used. Pumpkins are grown chiefly in Hungary, Poland, and lower Austria, also in America. In Hungary a distinction is made between pumpkins grown for feeding and those for human food.

MICROSCOPIC STRUCTURE.[4]

Seeds may usually be found in the cake with the naked eye. The microscopic identification of the seed elements is also not difficult. The

---

Kraftfutter und seine Verfälschung. Landw. Jahrb. 1884, **3**, 813. VAN PESCH: Kapokkuchen. Landw. Vers. Stat. 1896, **47**, 471. WINTON: Microscopy of Vegetable Foods. New York, 1915, 213.

[1] v. BRETFELD: Anatomie der Baumwoll- und Kapoksamen. Jour. Landw. 1887, **35**, 51.

[2] TH. KOSUTANY: Die Kürbiskernkuchen. Landw. Vers. Stat. 1893, **43**, 264–269.

[3] HARZ: Ueber Anbau und Verwerthung einiger Kürbissamen. Ztschr. Landw. Ver. in Bayern, 1879, März.

[4] FICKEL: Bot. Ztg. 1876, **34**, No. 47–50, 737. KATE BARBER WINTON: Winton's Microscopy of Vegetable Foods. New York, 1915, 400. v. HÖHNEL: Morpholog. Untersuchungen über die Samenschale der Cucurbitaceen. Sitzb. Wien. Akad. 1876, **73**. LOTAR: Anatomie comparé des organes végétatifs et des teguments seminaux des Cucurbitacées. Paris, 1881.

[illegible]

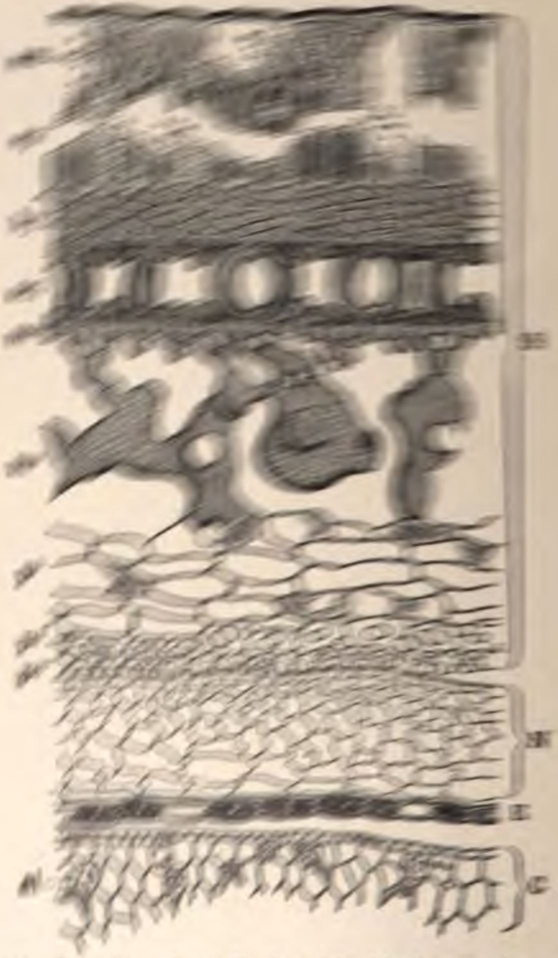


Fig. 215. Pumpkin. Outer Portion of Seed in Cross-section. X 160. (Kate G. Barber.)

S spermoderm consists of ep ribbed palisade cells of epidermis containing am starch grains, hy pitted hypodermal cells, scl sclerenchyma layer, m^1 pitted mesocarp cells, m^2 reticulated spongy parenchyma, p^1 parenchyma, p^2 spongy parenchyma, and p^3 inner epidermis; N perisperm; E endosperm consisting of aleurone cells; C cotyledon containing al aleurone grains.

215 and 216, *ep*) with branching ribs, small starch grains (*am*), the sclerenchyma layer with strongly thickened wavy walls (*scl*), and the remarkable reticulated spongy parenchyma(m^2).

GROUND OLIVE STONES.

Olive stones are the seeds of the olive tree (*Olea Europæa* L.) enclosed in the endocarp. They are used for the manufacture of olive-kernel oil. The residue from the oil presses is placed on the market in large quantities and serves chiefly for adulterating powdered spices and other food materials.

The stones are elongated ovoid or spindle-shaped, coarsely wrinkled on the surface, greenish, yellowish brown, or dirty gray-yellow, on an average 0.6 grams in weight, 15–18 mm. long, and 4–6 mm. thick.

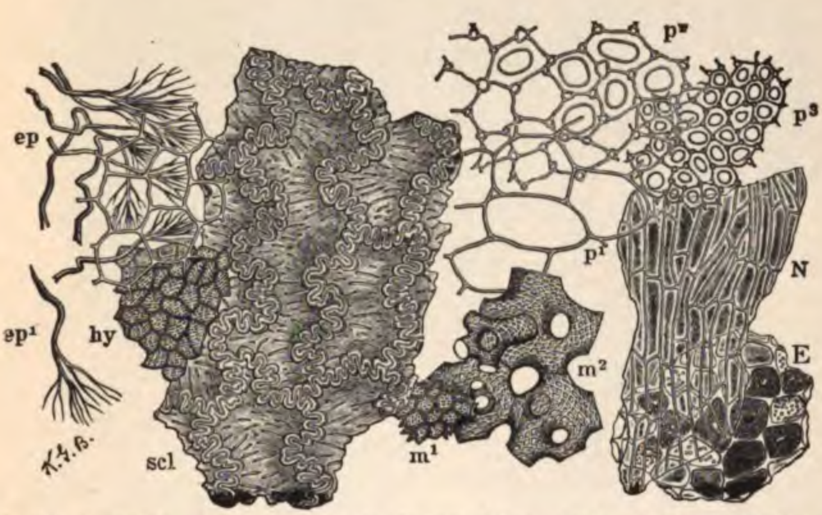


FIG. 216. Pumpkin. Seed Elements in Surface View. ×160. (KATE G. BARBER.) *ep* ribbed palisade cells of epidermis; *ep*¹ branching rib from epidermal cell; *hy* pitted subepidermal cells; *scl* sclerenchyma layer; *m*¹ pitted mesocarp cells; *m*² reticulated spongy parenchyma; *p*¹ parenchyma; *p*² spongy parenchyma; *p*³ inner epidermis of spermoderm; *N* perisperm; *E* endosperm.

Separated from the hard shell the seed is 9–11 mm. long, compressed, narrow, elongated, and has a soft, yellow spermoderm with strongly developed vascular bundles. The kernel is white or yellowish and consists of an oily endosperm in the middle of which is the embryo with a short radicle and two delicate three-nerved cotyledons. If the seed is broken off at one end, the embryo may be easily removed. The kernel is extraordinarily rich in fat.

MICROSCOPIC STRUCTURE.[1]

The hard shell, or **Endocarp**, is 2–3 mm. thick and consists almost entirely of **Stone Cells**. Near the surface ramify strongly developed vascular bundles with spiral vessels and porous elongated elements (Fig.

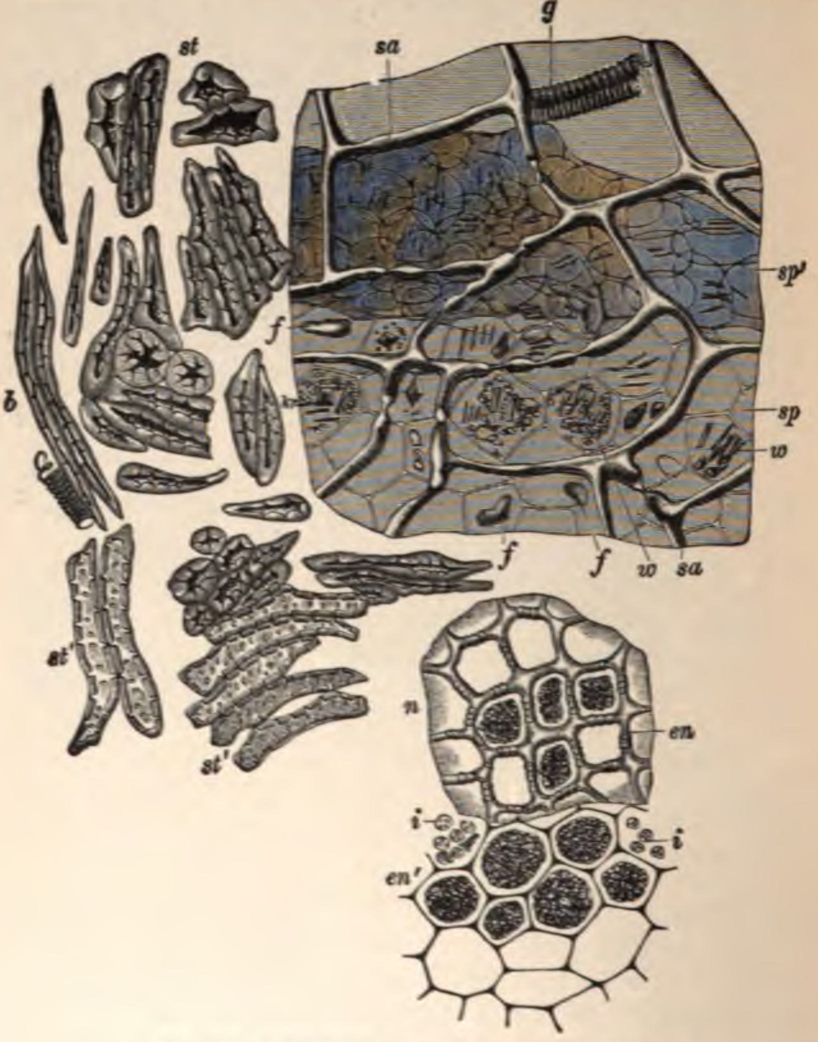


FIG. 217. Olive Stone Powder. (T. F. HANAUSEK.)

st stone cells of endocarp; *st'* same as last from innermost layers; *b* spiral vessel with sclerenchyma fibers; *sa* outer epidermis of spermoderm with underlying parenchyma *sp* and *sp'*; *w*, *kr* various forms of crystals; *g* spiral vessels; *en* peripheral layer of endosperm; *en'* inner layer of endosperm; *i* aleurone grains.

---

[1] T. F. HANAUSEK: Realenzyklopädie d. ges. Pharm. 2. Aufl., **9**, 477.

217, *b*). The stone cells in the outer layers are also for the most part elongated, the longer axis being usually parallel to the longer axis of the stone. The remainder of the shell consists, in addition to elongated stone cells, of others of rounded, rounded-polyhedral, ovoid, and various other forms (*st*, *st'*). Powdered olive stones contain this tissue in the form of hard yellow particles from which the individual stone cells may be isolated only after long treatment with hot potash. All the stone cells are more or less strongly thickened, richly pitted, laminated, and lignified. Examined in water they are colorless. In the innermost layers the stone cells are flattened and have thinner walls and broader lumens.

The **Spermoderm** consists of an epidermis and a parenchyma tissue through which pass the vascular bundles. The **Epidermal Cells** (Figs. 217 and 218, *sa*) are very conspicuous because of their large size and thick walls. They are irregular, mostly quadrangular, and have broad pits in the radial walls.

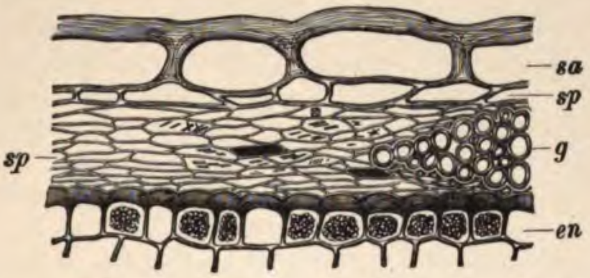


FIG. 218. Olive. Cross-section of Spermoderm and Endosperm. (T. F. HANAUSEK.) *sa* outer epidermis and *sp* parenchyma of spermoderm; *g* vascular bundles; *en* endosperm.

The **Parenchyma**, in the layers immediately beneath the epidermis, consists of rather large distinctly outlined elements (*sp* and *sp'*). Further inward the cells are thin-walled, compressed, in surface view rounded. The whole tissue is rich in raphides, whetstone- and rod-shaped crystals (fatty acid crystals?); occasionally crystalline forms resembling octahedrons are present. Spiral vessels occur in the vascular bundles.

Polyhedral, thin-walled, colorless cells make up the **Endosperm.** The outer layer shows in cross-section (Fig. 218, *en*) a strongly thickened outer membrane. In surface view distinct pits are evident in the radial walls, giving these a beaded appearance (Fig. 217, *en*). Oily protoplasm and aleurone grains with two or more globoids are the chief contents.

The tissues of the spermoderm and kernel are of little value in diagnosis since they are not easily found in mixtures; on the other hand, the stone cells of the hard shell are of great value. Among the striking stone cells are long narrow rods and spindles, elongated forms with rounded or pointed ends, bent forms, etc. (Fig. 217). They vary up to 100 μ in length. The flat porous stone cells from the inner layers of the shell are also of value.

DETECTION IN PEPPER.

Since ground olive stones are used in large amount for the adulteration of ground white and black pepper we will consider how this admixture can be detected by the microscopist, assuming that he is already familiar with the histological structure of pepper.[1]

A floating test for this admixture has been proposed for the use of those unfamiliar with microscopic methods, but it is of questionable utility. As described by **Girard** and **Dupré**,[2] the test consists in shaking the pepper with a mixture of equal parts of concentrated glycerine and water, in which mixture the particles of the olive kernel sink, while those of pepper float. The latter statement is certainly true, but it is also true that certain elements from the olive stones also occur with the pepper on the surface of the liquid.

Two simple tests are of value in the preliminary examination.

1. NEUSS' HYDROCHLORIC-ACID TEST.—If to a small portion of ground pepper is added concentrated hydrochloric acid, the resin contained in the perisperm dissolves to a gamboge-yellow liquid which also colors all the colorless starch cells yellow. Elements of pepper shells, as well as all foreign materials such as olive-stone meal, copra (cocoanut cake), palm nut cake, etc., remain uncolored and may be picked out from the powder with forceps and separately examined.

---

[1] GREENISH: The Microscopical Examination of Foods and Drugs. London, 1903, 255. T. F. HANAUSEK: Die Nahrungs- und Genussmittel aus dem Pflanzenreiche. Cassel, 1884, 102. *Idem:* Dammer's Lexikon der Verfälschungen. Leipzig, 1887, 2, 709. LEACH: Food Inspection and Analysis. New York, 1914, 433. MOELLER: Mikroskopie der Nahrungs- und Genussmittel. Berlin, 2 Aufl. 1905, 343. TSCHIRCH u. OESTERLE: Anatomischer Atlas. Leipzig, 1900, 103. VILLIERS et COLLIN: Traité des altérations et falsifications des substances alimentaires. Paris, 1900, 359. VOGL: Die wichtigsten vegetabilischen Nahrungs und Genussmittel. Berlin, 1889, 390. WINTON: Microscopy of Vegetable Foods. New York, 1915, 502.

[2] Analyse des matières alimentaires et recherche de leurs falsifications. Paris, 1894, 670.

2. Sulphuric-acid Test.—The fragments of genuine ground pepper treated with concentrated sulphuric acid and examined under a lens give the following color reactions: The shell of the pepper corn is colored brown, the starch cells of the perisperm dissolve to a yellow liquid, while the resin cells give a blood-red color.

NIGER CAKE.

Three species of *Compositæ*, namely niger, madia, and sunflower, yield fruits (achenes) of importance in oil production. Niger cake is derived from the fruits of *Guizotia Abyssinica* (L.) Cass. (=*G. oleifera* DC.), a plant grown extensively in Abyssinia and various parts of the East Indies. The light-brown to shining black fruits are 4–5 mm. long, 3–4 angled, and contain about 43 per cent of fat. The cake is rather soft and of a blackish color.

MICROSCOPIC STRUCTURE.[1]

Identification by microscopic examination presents no difficulties. The shell of the achene consists largely of **Pericarp**. The **Epicarp** (Figs. 219 and 220, *ep*) is made up of elongated cuticularized cells. Beneath this is a **Hypodermal Layer** of pigment cells (*hy*). These cells are rectangular, longitudinally elongated, and have light-colored walls and yellow-brown, rather thick contents with the reactions of tannin. In

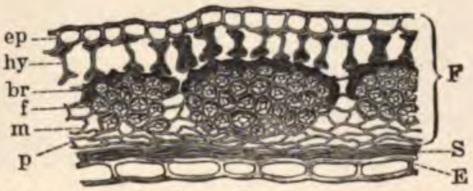


Fig. 219. Niger Seed (*Guizotia Abyssinica*). Cross-section of Hull. ×300. (Winton.)
F pericarp consists of *ep* epicarp, *hy* hypoderm, *br* pigment plates, *f* fiber bundles, *m* partitions, and *p* parenchyma; *S* spermoderm; *E* endosperm.

---

[1] Benecke: Anleitung zur mikroskopischen Untersuchung der Kraftfuttermittel auf Verfälschungen und Verunreinigungen. Berlin, 1886, 75. Böhmer: Die Kraftfuttermittel. Berlin, 1903, 464. *Idem:* Dammer's Lexikon der Verfälschungen. 1887, **2**, 685. *Idem:* König's Die Untersuchung landwirtschaftlich und gewerblich wichtiger Stoffe. 3. Aufl. 1906, 359. T. F. Hanausek: Wiesner's Die Rohstoffe des Pflanzenreiches. 2. Aufl. 1903, **2**, 870. Pfister: Oelliefernde Compositenfrüchte. Landw. Vers. Stat. 1894, **43**, 441. Winton: The Anatomy of Certain Oil Seeds with Especial Reference to the Microscopic Examination of Cattle Foods. Conn. Agr. Exp. Sta. Rep. 1903, 175. *Idem:* Microscopy of Vegetable Foods. New York, 1915 200.

cross-section these cells strikingly resemble the hour-glass cells found in the spermoderm of legumes.

Like most composite fruits the pericarp contains a thick, hard layer made up of bundles of strongly thickened **Sclerenchyma Fibers** (*f*) with diagonally fissured pits, separated from each other by rows of parenchyma cells reminding one of the medullary rays of wood.

Between the hypoderm and the fiber layer lie the brown to black **Pigment Plates** (*br*), which also occur isolated in the cake in the form of black, often toothed, strips. These are marked similarly to a tortoise shell and show numerous pores. The material is insoluble in chromic acid, sulphuric acid, and boiling alkali. The author[1] has shown that the similar pigment plates of the sunflower consist of carbon resulting from the disorganization of peculiar cells by a kind of humefication process. In the earlier stages of growth the cells bear numerous protuberances on the outer and radial walls.

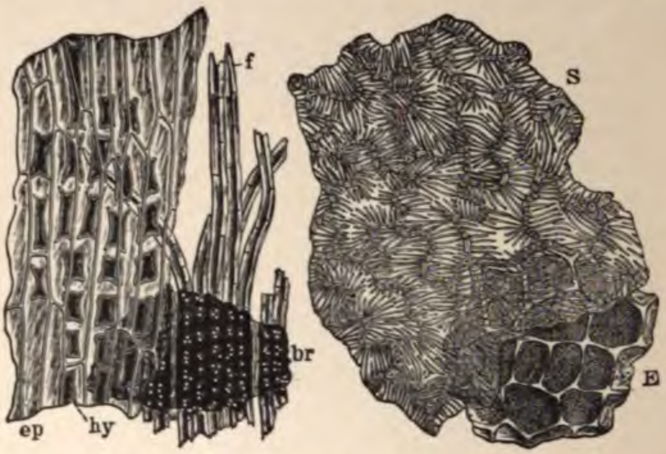


FIG. 220. Niger Seed. Pericarp, Spermoderm, and Endosperm in Surface View. ×300. (WINTON.)

ep epicarp; *hy* hypoderm; *br* pigment plates; *f* fiber bundles; *S* spermoderm; *E* endosperm.

The fiber bundles are almost always intact in the cake and are covered with fragments of the pigment plates.

The inner layer of the pericarp consists of several cell layers of compressed **Parenchyma**.

---

[1] T. F. HANAUSEK: Zur Entwickelungsgeschichte des Perikarps von *Helianthus annuus*. Ber. Deutsch. Bot. Gesell. 1902, **20**, 449.

Closely united to the pericarp is the thin **Spermoderm** (*S*) consisting of a characteristic **Epidermis**, with wavy walls pierced by delicate elongated pits often showing a fan-shaped arrangement, and inner layers of **Obliterated Parenchyma**. A single layer of more or less quadrate aleurone cells constitutes the **Endosperm** (*E*).

The tissues of the **Cotyledons** contain oily protoplasm and aleurone grains in thin-walled cells. After gentle warming with alcoholic potash the cell contents often contract into lumps.

MADIA CAKE.

Madia sativa Mol. occurs native in Chile and in the United States from California to Oregon. The plant is also cultivated in Europe, for example in Baden, near Vienna, but does not appear to have attained much importance. The microscopic elements of the fruit[1] and cake (Figs 221 and 222) are similar to those of niger fruit, but the epicarp cells have porous walls, and the hypoderm cells of the pericarp are not hourglass-shaped in section, and the epidermal cells of the spermoderm are not wavy in surface view.

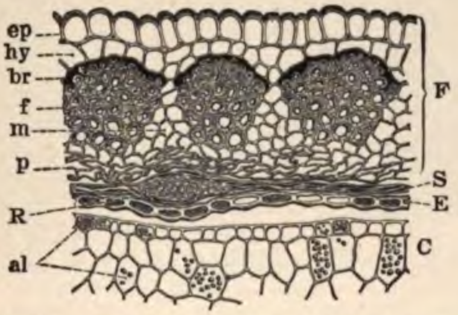


FIG. 221. Madia (*Madia sativa*). Cross-section of Outer Portion of Fruit. ×160. (WINTON.)

F pericarp consists of *ep* epicarp, *hy* hypoderm, *br* pigment plates, *f* fiber bundles, *m* partitions, and *p* parenchyma; *S* spermoderm, with *R* raphe; *E* endosperm; *C* cotyledon containing *al* aleurone grains.

SUNFLOWER CAKE.

This cake[2] is obtained from the fruits ("seeds") of the common sunflower (*Helianthus annuus* L.), which is cultivated for its fruit chiefly in Hungary, Italy, and Russia. The fruits have a brittle pericarp which easily splits parallel to the axis. According to KOSUTANY the shell (pericarp) is removed by one of two methods previous to extracting the oil.[1] The first method consists in running the dry fruit beween millstones. In order to facilitate the separation of the shell, the upper stone should be as sharp as possible and the under stone should be prepared with a mixture of clay and hogs' bristles or else with cork. The shells are removed by a rotary blower. After passing through the mill the kernels are separated from the unshelled fruits by sifting and the latter are passed a second time through the mill. By the second method the fruits are crushed by rollers and separated from the shells by sifting.

---

[1] See references under niger cake, p. 375.

[2] TH. KOSUTANY: Ueber Sonnenblumenkuchen. Landw. Vers. Stat. 1893, **43**, 253–263. The fruits are designated by him "seeds" and the pericarp "seed coat".

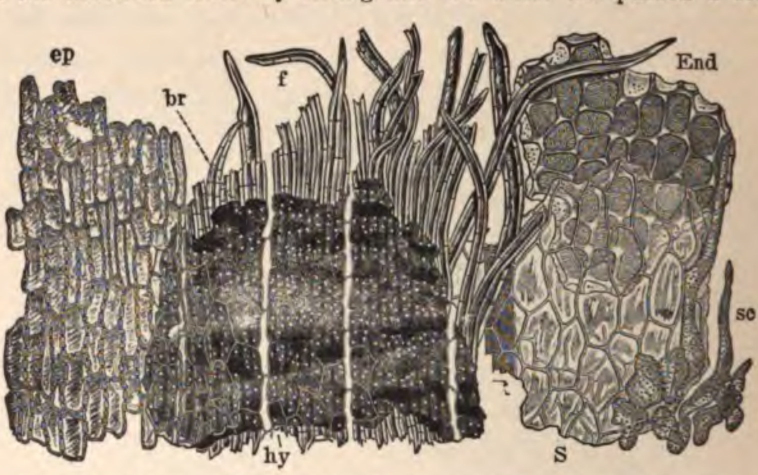


FIG. 222. Madia. Elements of Fruit in Surface View. × 160. (WINTON.)
ep epicarp; *hy* hypoderm; *br* pigment plates; *f* fiber bundles; *S* spermoderm with *R* raphe bundle; *sc* pitted cells at base of spermoderm; *End* endosperm.

The shelled kernels are ground in vertical or roller mills, warmed, and pressed. Sunflower oil is used as an edible oil (lenten oil of communicants of the Greek church). Hungarian sunflower cake comes into the market from Budapest and Maria Theresiopel. Other commercial varieties are obtained from Russia, Italy, and the East Indies.

MICROSCOPIC STRUCTURE.[2]

The structure differs little from that of niger and madia fruits. The **Pericarp** (Fig. 223, *I*) has five layers. Especially characteristic is the

---

[1] *Loc. cit.* 759.

[2] T. F. HANAUSEK: Zur Entwicklungsgeschichte des Perikarps von ***Helianthus annuus.*** Ber. Deutsch. Bot. Gesell. 1902, **20**, 449. GREGOR KRAUS: Ueber den **Bau** trockener Peri-

Epicarp (*ep'*) consisting of large, rather thick-walled cells with pitted radial walls and numerous hairs (*II*) which are well preserved at the base of the fruit, but in other parts are largely broken off. Stomata are absent. The hairs are sword-shaped, unicellular, often up to 500μ long, and occur united in pairs. The author has shown that these hairs are attached at the base to a "foot cell" (*f*)—one to the top of this cell, the other to the side. The pigment in the black or striped fruits occurs in the epicarp and the underlying layers.

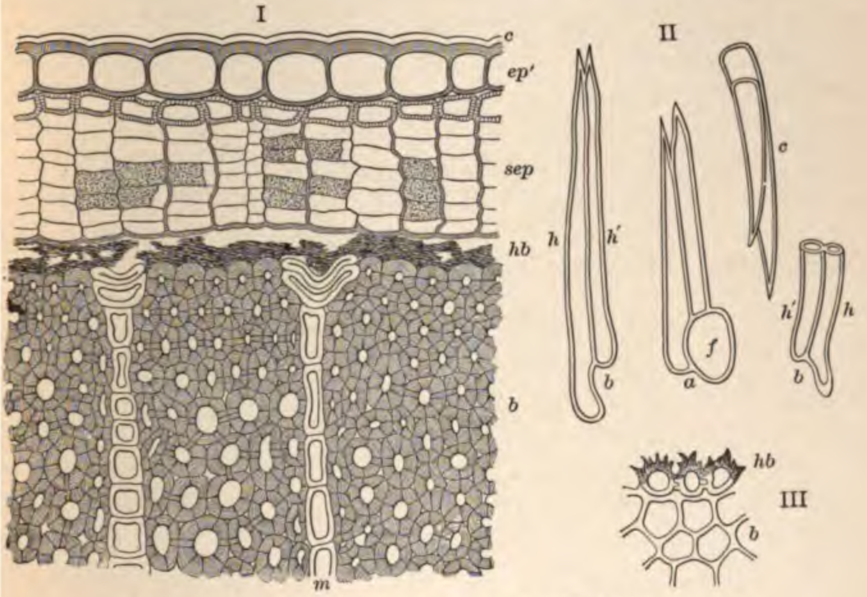


FIG. 223. Sunflower (*Helianthus annuus*). (T. F. HANAUSEK.)

I Cross-section of pericarp: *ep'* epicarp with *c* cuticle, *sep* parenchyma, *hb* pigment plates, *b* fiber layer, *m* partitions.—*II* hairs: *a* attached to *f* foot cell, *b* without foot cell, *c* seen from side.—*III* cross-section from immature fruit showing *hb* cells which later form the pigment plates and *b* undeveloped fibers.

Beneath the epicarp is a **Parenchyma** (*sep*) several cells thick with numerous pits and a shagreen-like appearance in surface view.

Pigment Plates (*I hb*) which, like those found in the fruit of niger and madia, consist of carbon resulting from the humefication of a cell layer (*III hb*) are present in dark or striped fruits.

---

karpien. Inaug. Diss. Leipzig, 1866, 62. MOELLER: Mikroskopie der Nahrungs- und Genussmittel. Berlin, 2. Aufl. 1905, 329. WINTON: Microscopy of Vegetable Foods. New York, 1915, 195.

The **Fiber Layer** (*b*) consists of strongly thickened porous sclerenchyma fibers united in bundles and between these, rows of parenchyma cells resembling medullary rays (*m*). Small vascular bundles occur at the inner boundaries of the bundles.

The inner portion of the pericarp consists of a loose delicate **Parenchyma** with a thin inner epidermis (endocarp).

The **Spermoderm** may be easily separated from the seed as a delicate glassy membrane. It consists of two layers.

On the inner side of the last is a single layer of **Aleurone Cells** constituting the **Endosperm**.

The **Cotyledons** are bifacial and have a double or triple palisade layer. They contain oil and aleurone grains.

Characteristic of sunflower cake is the epicarp with the twin hairs.

SESAME CAKE.

The seeds of *Sesamum Indicum* (L.) DC. yield not only an excellent edible oil, but also a valuable oil cake. At the present time the seeds of an African species, *Sesamum radiatum* Schum. et Thonn. (=*S. occidentale* Heer et Regel), are found on the market and often are mixed with the seeds of the Indian species. BENECKE[1] has distinguished between sesame cake from "double-husked" seed and that from common seed, both of which he regarded as from *S. Indicum*, but the former contained the fruit husk. However, in a later paper on sesame seed,[2] he has shown that "double-husked" cake is derived from *S. radiatum* and is more appropriately designated "thick-shelled" sesame cake.[3] Later we will note the reasons for this designation.

The seeds of *S. Indicum* are whitish, clear yellow, or brownish (in the form *S. orientale* L., reddish to black), strongly flattened, ovate, on the average 3 mm. long, 2 mm. broad, and 1 mm. thick. A marked characteristic is the ridged border, which originates in the hilum and is present on both of the broad sides, but is more pronounced on the flatter of these sides. If one of the broad sides is strongly convex this side lacks the ridged border. The hilum is situated on the pointed end, forming a slight elevation.

---

[1] *Loc. cit.* 57.

[2] Die verschiedenen Sesamarten und Sesamkuchen des Handels. Phar. Centh. 1887, 8, 545.

[3] See HEBEBRAND: *loc. cit.* 63.

MICROSCOPIC STRUCTURE.[1]

The seed consists of a thin shell, a delicate skin (endosperm), and a large embryo with two flat cotyledons.

The **Spermoderm** is of very simple structure and is characterized by a peculiar formation consisting of calcium oxalate. We find combined in the outer layer the characters of an epidermis, a crystal layer, and a pigment layer. This **Epidermis** (Figs. 224 and 225, *ep*) consists of thin-walled, non-lignified palisade cells which in cross-section are rectangular, rounded at the outer end, and in surface view, polygonal. When

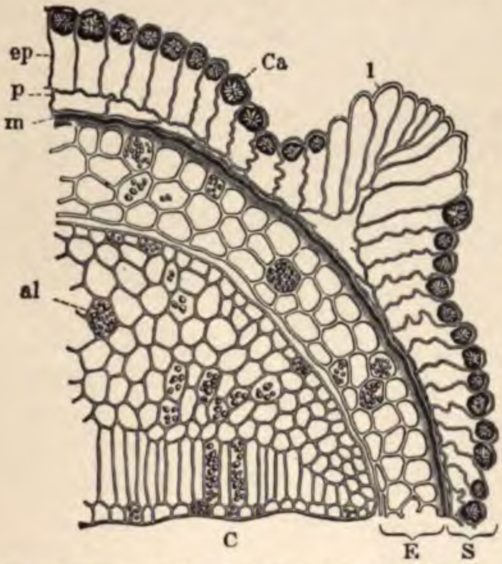


FIG. 224. Sesame (*Sesamum Indicum*). Cross-section of Portion of Seed. × 160. (WINTON.)

S spermoderm consists of *ep* epidermal cells with *Ca* crystal masses, *l* epidermal cells of ridges, *p* parenchyma, and *m* yellow membrane; *E* endosperm; *C* cotyledon containing *al* aleurone grains.

---

[1] BENECKE: Anleitung zur mikroskopischen Untersuchung der Kraftfuttermittel auf Verfälschungen und Verunreinigungen. Berlin, 1886, 57. BÖHMER: Die Kraftfuttermittel. Berlin, 1903, 503. *Idem:* Dammer's Lexikon der Verfälschungen. Leipzig, 1887, **2**, 683. *Idem:* König's Die Untersuchung landwirthschaftlich und gewerblich wichtiger Stoffe. Berlin, 3. Aufl. 1906, 348. FLÜCKIGER: Zur Kenntniss des Sesamsamens. Schweiz. Wochschr. Pharm. 1865, No. 37, 282. HEBEBRAND: Ueber den Sesam. Landw. Vers. Stat. 1899, **51**, 45. WIESNER: Die Rohstoffe des Pflanzenreiches. 2. Aufl. 1903, **2**, 768. WINTON: The Anatomy of Certain Oil Seeds with Especial Reference to the Microscopic Examination of Cattle Foods. Conn. Agr. Exp. Sta. Rpt. 1903, 175. *Idem:* Microscopy of Vegetable Foods. New York, 1915, 219. See also bibliographies in WIESNER and WINTON.

in surface view show not only the pigment but, after boiling in water, the crystal masses.

Sesame oil is detected by the well-known Baudouin test, which has been modified by VILLAVECCHIA and FABRIS.[1] This test may also be employed microchemically by treating sections of the seed with hydrochloric acid and alcoholic furfurol solution, after which the embryo tissues become rose-red.[2] The constituent of sesame which gives this reaction is regarded by BENEDIKT as a resin which is without odor, soluble in alcohol, ether, and acetic acid, but insoluble in water and mineral acids.

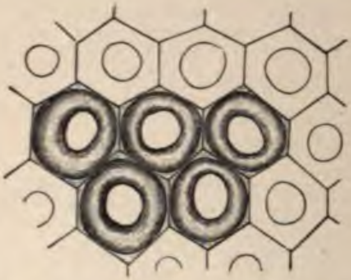


FIG. 228. Sesame (*S. radiatum*). Palisade Epidermis of Spermoderm in Surface View. Cells as seen with High and Low Focus. ×450. (T. F. HANAUSEK.)

LINSEED CAKE AND LINSEED MEAL.

Ground linseed from which none of the oil has been extracted is used to a limited extent in medicine and for other purposes; the cake and the ground cake, known as linseed meal, are valuable cattle foods.

Linseed frequently contains impurities. The Prussian product contains much grass seed, rape seed, and dust, and yields little oil and poor cake. North and South American cakes also contain more or less weed seed, while the Russian product is said to be quite free from contamination. South Russian linseed yields 30 per cent of oil and the richest cake as regards protein. According to HASELHOFF and VAN PESCH,[1] almost all linseed contains seeds of common and German rape, wild radish, mustard, false flax, hemp, cockle, bindweed, species of *Polygonum*, spurrey, parts of grasses, clover husks, and clover dodder. Linseed cake is also often adulterated.

---

[1] As described by the German oleomargarine law the reaction is as follows: "If a mixture of 0.5 part by volume of sesame oil and 99.5 parts of cottonseed or peanut oil are shaken with 100 parts of fuming hydrochloric acid (sp. gr. 1.19) and a few drops of 2 per cent alcoholic solution of furfurol, the acid solution which settles below the oil layer should show a distinct red coloration. The furfurol must be colorless. (See Vrtljber. in Apoth. Ztg. Berlin, 1897, 475.)

[2] Furfurol (furfur=small, oleum=oil) is the aldehyde of pyromucic acid and is formed in the dry distillation of sugar or by distilling 1 part of bran, 1 part of concentrated sulphuric acid, and 3 parts of water. It has the formula $C_5H_4O_2$ ($=C_4H_3O \cdot COH$) and is a liquid with the odor of bitter almond and cinnamon oil.—The Molisch sugar reaction (see p. 124) depends on the formation of furfurol from carbohydrates by the action of concentrated sulphuric acid and the so-called pine-sawdust reaction depends on the same principle. The latter consists in moistening the sawdust with hydrochloric acid and then with carbolic acid, after which, on exposure to the sunlight, it becomes blue.

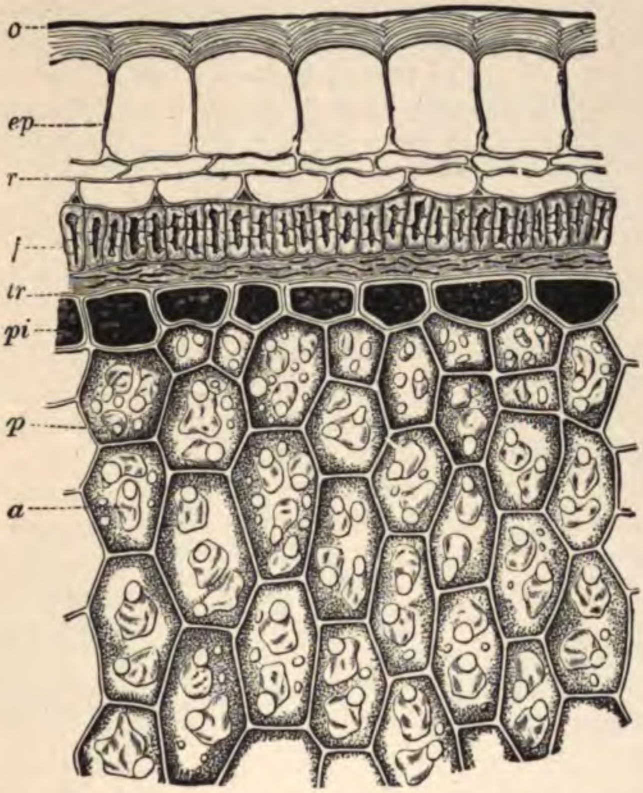


FIG. 229. Linseed (*Linum usitatissimum*). Cross-section of Outer Portion of Seed. (TSCHIRCH.)

ep outer epidermis (swollen) with *c* cuticle; *r* two layers of round cells; *f* sclerenchyma fibers; *tr* cross-cells; *pi* tannin (pigment) cells; within the last several layers of the endosperm with *p* oily protoplasm and *a* aleurone grains.

---

[1] HASELHOFF: Ueber die Fabrikation und Beschaffenheit des Leinkuchens bezw. des Leinmehles. Landw. Vers. Stat. 1892, **41**, 54–72. F. J. VAN PESCH: Ueber Fabrikation, Verunreinigungen von Leinkuchen und deren Nachweis. *loc. cit.* 73–93.

Four processes are employed for obtaining the oil.[1] The original process employing stamps has been largely discarded for more practicable methods.

In the second process, known as the Neusser or French system, the unpurified seed is pressed between chilled rollers, ground in a mill with water, and heated either in iron kettles over a fire with stirring or in jacketed steam kettles, and pressed in coarse cloths. The cake after the first pressing is reground, warmed, and again pressed. The second cake thus obtained, containing 7–9 per cent of oil, is the linseed cake of commerce.

In the third process American or Anglo-American presses are used. After crushing between rollers the seed is scalded in a heating apparatus with superheated steam. The seeds after this treatment are lighter in color, odorless, and may be pressed into a very hard cake.

The fourth process depends on extraction with benzine. After grinding between steel rollers, the seed is placed in an hermetically sealed iron box and covered with benzine. The benzine solution of the oil is removed by a syphon.

The method of manufacture exerts considerable influence on the quality of the cake, but on this point we have little accurate information.

MICROSCOPIC STRUCTURE.[2]

The examination of linseed products is comparatively simple, but requires care. The seed is flattened ovoid, with a brown or, in the case of Indian seed, a yellowish-white spermoderm, a thin endosperm, and a straight embryo with two cotyledons. The delicate colorless tissues of the **Cotyledons** (Fig. 230, ep^2, *mes*) and the thick-walled cells of the **Endosperm** (*E*) contain a large amount of oily protoplasm and aleurone grains (*al*) with distinct crystalloids. Although these tissues, making up the bulk of the cake and the meal, are not characteristic, the products may be readily and certainly identified by the elements of the **Spermoderm**. This consists of five layers: An **Epidermis** (Figs. 229, ***ep***, and 230, ep^1), the cells of which have mucilaginous outer and side walls, covers a parenchyma layer of **Round Cells** or rounded polyhedral cells with thick yellow walls (*r*). Next follows a single **Fiber Layer** (*f*) with lignified and richly pitted elements arranged longitudinally as regards the axis of the seed. Crossing the last at right angles are the thin-walled, elongated **Cross-cells** (*tr*) of the next layer. The inner layer is composed of **Pigment Cells** (*pig*) which in surface view are highly characteristic because of their more or less square or polygonal form, their thick, pitted, colorless walls and their almost opaque, homogeneous, hard, red-brown contents. These pigment cells, as well as the isolated brown contents, which still preserve the forms of the cells, are always found in the cake and meal and, together with the fiber bundles, the round parenchyma cells, and the mucilaginous epidermis, are of great value in diagnosis.

---

[1] Haselhoff: *loc. cit.* 58.

[2] Jules van den Berghe: Tourteaux et farine de Lin, composition, impuretés, falsifications. Brüssel. (Cited by van Pesch: *loc. cit.* 79). Böhmer: Die Kraftfuttermittel. Berlin, 1903, 434. Collin et Perrot: Les résidus industriels. Paris, 1904, 195. Kobus: Landw. Jahrb. 1884, 120. Wiesner: Die Rohstoffe des Pflanzenreiches. 2. Aufl. 1903, **2**, 748. Winton: Microscopy of Vegetable Foods. New York, 1915, 202. See also bibliographies in Wiesner and Winton.

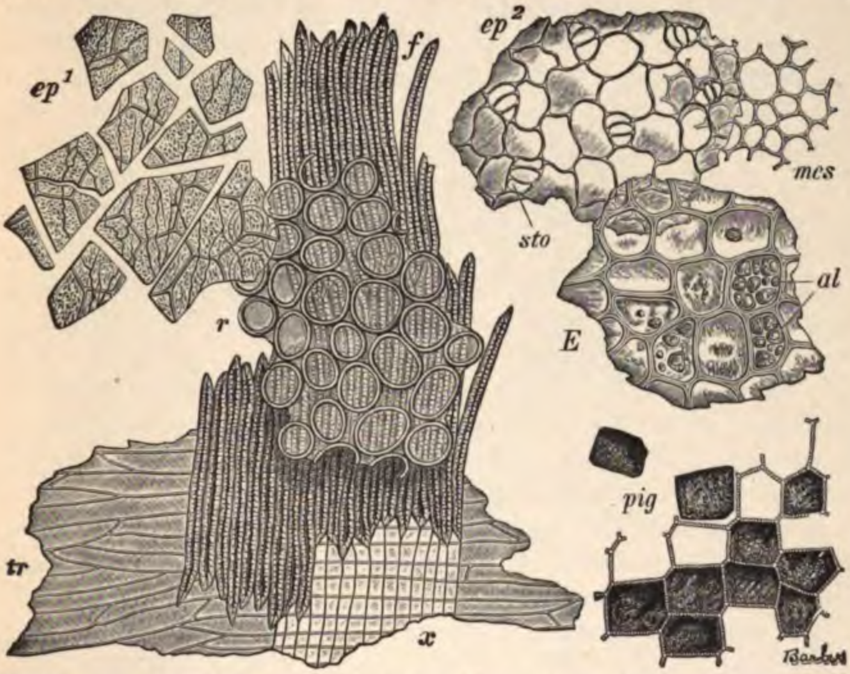


FIG. 230. Linseed. Elements in Surface View. ×300. (KATE G. BARBER.)
ep^1 epidermis of spermoderm; *r* round cells; *f* fiber layer; *x* middle lamellæ of fiber layer; *tr* cross cells; *pig* pigment cells; *E* endosperm with *al* aleurone grains; *ep*^{2} epidermis of cotyledon with *sto* immature stomata; *mes* mesophyl.

PEANUT CAKE.

The straw-yellow, cylindrical, usually constricted fruits (pods) of the peanut (*Arachis hypogæa* L.) ripen underground and contain 1–3 seeds which are elongated cylindrical or elongated ovoid, at one end diagonally flattened and short-beaked, at the other end rounded or diagonally flattened, and have a thin copper-colored, brownish, or violet-brown skin and a white kernel or embryo.

Both the fruits[1] and the shelled nuts are placed on the market as raw materials for oil production, the shelled nuts being obtained chiefly from Congo, Loango, Mozambique, Zanzibar, and the Coromandel coast, although a better product is obtained from nuts which are transported whole, thus protecting the seeds from damage during transportation.

The manufacture of the oil is carried out as follows:[2] After the unshelled nuts are well cleaned by brushes, etc., they are broken by rollers and sifted on oscillating screens, thus removing the lighter pieces of shell. The breaking and sifting processes also remove the most of the "germs" (radicles) and many of the brown skins (spermoderm). When the seeds are broken up sufficiently they are placed in a cylindrical press in thin layers separated by horse-hair cloths. The first pressing is carried on with low pressure and the resulting cake is very loose and easily disintegrated. This cake is broken up and finely ground in vertical mills with the addition, from time to time, of water and of the meal that has been forced through the holes of the press. The ground cake is then subjected to a second pressing.

If table oil is desired, the finely ground seeds are brought directly into the press and pressed cold; if, however, the oil is designed for technical purposes the seed is warmed before the first pressing.

The cake is gray-white (Hamburg) to gray-brown (Marseilles). Yellow or gray-yellow cake, according to UHLITZSCH, is suspicious, since it is usually made from nuts which have become yellow through fermentation.

African nuts (Rufisque and Gambia) yield the best cake, Italian and Spanish, a very good grade, but the cake from Indian nuts is inferior. Good cake has an agreeable taste and is eaten by the workmen. It is one of the most easily digested and most valuable of concentrated feeds. Roasted peanuts are also used as a coffee substitute (Austrian bean coffee).[3]

---

[1] Variously known as pea, earth, ground, Mani, Mandubi, Aschanti, or Manila nuts, pistaches de terre, etc.

[2] P. UHLITZSCH: Rückstände der Erdnussölfabrikation. Landw. Vers. Stat. 1892, **41**, 385-431.

[3] About 4,000,000 bushels of peanuts are annually produced and consumed in the United

MICROSCOPIC STRUCTURE.[1]

In order to distinguish the different layers of the **Spermoderm** in cross-section, it is necessary to treat the preparation successively with dilute hydrochloric acid and potash or with Javelle water. Three distinct layers are present. The **Epidermis** (Figs. 231 and 232, *aep*) consists of cuticularized cells which in cross-section are quadrangular and in surface view sharply polygonal. Both the outer and the side walls are strongly thickened, while the inner walls are thin. The thickenings of the outer membranes consist of longitudinal strips which, as seen in surface view, extend into the lumen of the cell like teeth. In cross-section the side walls are triangular owing to the gradual diminution of the thickening.

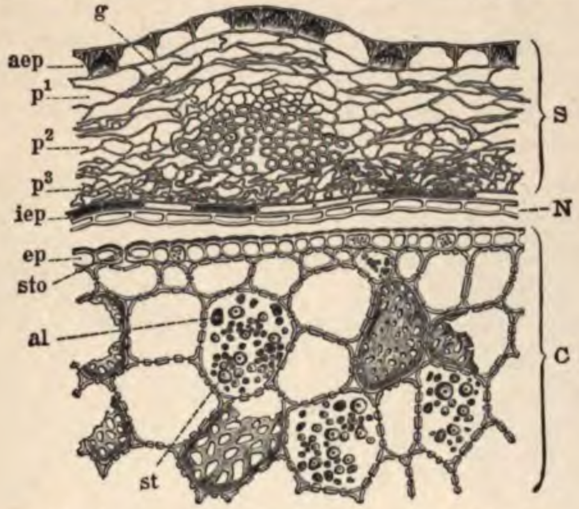


FIG. 231. Peanut (*Arachis hypogæa*). Outer Portion of Seed in Cross-section. × 160. (WINTON.)

S spermoderm consists of *aep* outer epidermis, p^1 parenchyma, p^2 and p^3 spongy parenchyma, and *iep* inner epidermis; *g* fibro-vascular bundle; *N* perisperm; *C* cotyledon consists of *ep* epidermis with *sto* stoma, and the porous parenchyma cells containing *st* starch grains and *al* aleurone grains.

States, the larger part being roasted and sold on the street or else used in the manufacture of confectionery. See HANDY: U. S. Dept. Agr. Farm. Bull. 25. (A. L. W.)

[1] BÖHMER: Die Kraftfuttermittel. Berlin, 1903, 514. COLLIN et PERROT: Les résidus industriels. Paris, 1904, 195. KOBUS: Kraftfutter und seine Verfälschung. Landw. Jahrb. 1884, **13**, 813. UHLITZCH: Rückstände der Erdnussölfabrikation. Landw. Vers. Stat. 1892, **41**, 385. WINTON: The Anatomy of the Peanut with Special Reference to its Microscopic Identification in Food Products. Conn. Agr. Exp. Sta. Rpt. 1904, 191. *Idem:* Microscopy of Vegetable Foods. New York, 1915, 269. WIESNER: Die Rohstoffe des Pflanzenreiches. 2. Aufl. 1903, **2**, 734. See also bibliographies in WIESNER and WINTON.

The **Subepidermal Layer** and a few succeeding layers consist of parenchyma without intercellular spaces (p^1). Further inward the tissue changes to a yellow-brown, typical **Spongy Parenchyma** rich in intercellular spaces (p^2, p^3) through which pass the bundles with spiral vessels (*g*). An **Inner Epidermis** (*iep*) with yellow-brown contents completes the spermoderm.

Adjoining the preceding layer is a hyaline coat with colorless, laminated cells which swell greatly in potash (*N*). This is the remains of the nucellus, and must therefore be classed as **Perisperm.** Each of the **Cotyledons** (Fig. 231, *C*) consists of two epidermal layers and a mesophyl of large parenchyma cells. The **Outer Epidermis** (Figs. 231 and 232, *ep*; Fig. 233) is made up of elongated cells with strongly thickened outer walls and numerous stomata (*st*) each with two accompanying cells (*n*). Small starch grains (Fig. 233, *am*) occur in the guard cells of the stomata. In the subepidermal layer the parenchyma of the cotyledons consists of small cells, in the remaining parts of large rounded polyhedral cells, all of which after removal of the contents with Javelle water show round or elliptical pits (Figs. 231 and 234). Starch, aleurone grains, and oil are the visible contents. If a section is partially freed from fat and treated with iodine solution, the starch grains are colored blue, the aleurone grains golden yellow, the fat drops pale yellow. The starch grains are usually globular, 3–12μ in diameter; the larger forms are ovoid and have a central hilum. The aleurone grains are round, ovoid,

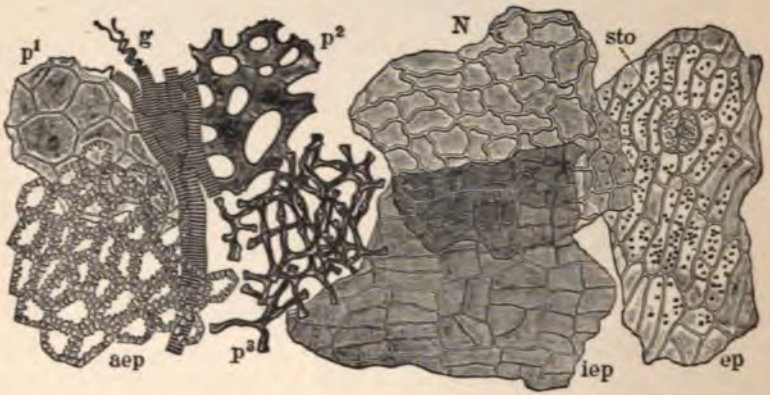


FIG. 232. Peanut. Elements of the Seed in Surface View. ×160. (WINTON.)
aep outer epidermis of spermoderm; p^1 parenchyma; p^2 and p^3 spongy parenchyma; *g* bundle; *iep* inner epidermis of spermoderm; *N* perisperm; *ep* epidermis of cotyledon with *sto* stoma.

or quite irregular in form, and of two sizes: (1) small (4–8μ), and (2) large (10–13μ), often with numerous globoids.

Again we have a seed with the most characteristic tissues in the spermoderm. These tissue elements occur even in cake prepared from carefully shelled nuts. Of the tissues of the kernel, the parenchyma cells of the cotyledons, with the rather large pores, often arranged in a circle, are also characteristic. Especially valuable in diagnosis are the starch grains which are not found in most oil cakes.

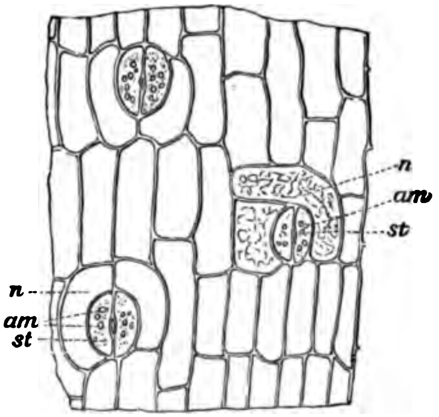


FIG. 233. Peanut. Epidermis of Cotyledon in Surface View. ×450. (T. F. HANAUSEK.) *st* guard cells of stomata with *am* starch grains; *n* accompanying cells.

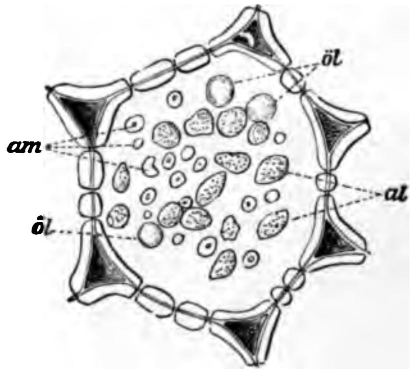


FIG. 234. Peanut. Single Cell of Cotyledon after Removal of Part of the Fat with Ether, and Treatment with Iodine Solution. ×700. (T. F. HANAUSEK.) *am* starch grains; *öl* oil drops; *al* aleurone grains.

RAPE CAKE.

Oil cakes are obtained from the seeds of common rape (*Brassica Napus* L., order *Cruciferæ*) and German rape (*B. Rapa* L.). Often they are contaminated with seeds of wild radish (*Raphanus Raphanistrum* L.), charlock, and black mustard, which render the cake injurious to cattle. If either of the last two seeds is present, a strong smell of mustard oil is evident after stirring with warm water and cooling.

MICROSCOPIC STRUCTURE.[1]

It is not a difficult matter to determine that a cake is made from a cruciferous seed. The **Palisade Cells**, also known as beaker cells, which in surface view are sharply polygonal with small round lumens, serve well this purpose, but the distinction of common rape, German rape, and black mustard from each other presents great difficulties. In common rape the lumen of the palisade cells is usually broader than the double walls about them; in German rape the lumen is circular and much narrower than the double walls; black mustard has smaller palisade cells than either of the rapes.

Benecke's method serves well in orienting. It is as follows: Place a teaspoonful of the meal in a capsule, add 15 cc. of water, stir, add an equal volume of concentrated hydrochloric acid, stir again, heat, with constant stirring, to boiling, add cold water, filter, wash well with water, squeeze out as much of the water as possible from the residue, place in a porcelain dish, add about 15 cc. of glycerine, and heat with slow stirring.

Surface preparations show that the palisade cells of both common and German rape are polygonal in outline, but in the case of German rape some of the cells are higher than the others, forming polygonal reticulations. Black mustard seed also has reticulations, but the individual cells are only one-half as large as those of German rape. The seeds of false flax (*Camelina sativa* L.)[2] and several species of *Cruciferæ* grown in India[3] yield oil and oil cakes of commercial importance.

---

[1] Böhmer: Die Kraftfuttermittel. Berlin, 1903, 420. Collin et Perrot: Les résidus industriels. Paris, 1904, 150. J. Schröder: Untersuchungen der Samen der Brassica-Arten und Var. Landw. Vers. Stat. 1871, **14**, 179. Sempolowski: Beiträge zur Kenntniss der Samenschale. Inaug. Diss. Leipzig, 1874, 43. Winton: Microscopy of Vegetable Foods. New York, 1906, 180.

[2] Nevinny: Die Samen von *Camelina sativa*. Ztschr. Nahr. Unters. Hyg. Wien, 1887, **1**, 81. F. J. van Pesch: Leindotter-Kuchen. Landw. Vers. Stat. 1892, **41**, 94. Winton: *loc. cit.*, [illegible]

[3] Kinzel: Ueber die Samen einiger Brassica- und Sinapis-Arten, mit besonderer Berücksichtigung der ostindischen. Landw. Vers. Stat. 1899, **52**, 169. Winton: *loc. cit.*, 188, 189.

POPPY CAKE.

Poppy cake is obtained from the seeds of the garden poppy (*Papaver somniferum* L.). The percentages of fat in the product differ widely and the controversy over its value as a cattle food is not yet decided. Since, however, according to SACC, the cake is free from alkaloids and contains at least 30 per cent of protein and on the average 9 per cent of fat, it appears to be well suited for feeding.

Both poppy cake and poppy-seed meal contain more or less perfect seeds, or else pieces of seeds of considerable size, which are easily recognized under the lens by their kidney shape and the very elegant and somewhat regular reticulations. On the surface the seeds are yellowish white, gray-blue, or blackish blue. The length varies from 1 to 1.5 mm. and the average weight of 200 seeds is 0.1 gram. The somewhat raised hilum is in the middle of the hollowed-out side, and the chalaza, in the form of a yellowish elevation, lies near the hilum toward the broad end of the seed. Within the thin spermoderm is the white, fatty endosperm and in the middle of the last is embedded the almost cylindrical embryo, bent so as to conform to the kidney-shape of the seed, with radicle and cotyledons of about equal length.

MICROSCOPIC STRUCTURE.[1]

Owing to the small size of the seed and the shrivelled condition of the skin, the microscopic investigation of the seed, and particularly of the **Spermoderm**, presents considerable difficulties.

The **Epidermis** (Figs. 235 and 236, *ep*) of the spermoderm is composed of very large, in surface view polygonal, mostly six-sided, tabular cells. The side walls correspond to the reticulations of the seed while the middle of the cell is collapsed so that the outer walls lie close to the inner.

The subepidermal **Crystal Layer** (*k*) or oxalate layer consists of very thin-walled parenchyma cells closely packed with crystal sand of calcium oxalate. If the contents are removed from the cell and distributed by gentle pressure with the cover glass, large rhombohedron-like crystals are also evident.

The third or **Fiber Layer** (*f*) is made up of fiber cells with a lumen which in cross-section appears as a narrow cleft. Chlorzinc iodine colors the walls violet.

---

[1] BÖHMER: Die Kraftfuttermittel. Berlin, 1903, 472. WIESNER: Die Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903, 2, 711. WINTON: The Anatomy of Certain Oil Seeds, with Especial Reference to the Microscopic Examination of Cattle Foods. Conn. Agr. Exp. Sta. Rpt. 1903, 175. *Idem:* Microscopy of Vegetable Foods. New York, 1915, 225. See also bibliographies in WIESNER and WINTON.

Cross-cells (*q*) form the fourth layer and **Netted Cells** (*n*) of elegant appearance the fifth layer. The netted cells contain the pigment to which the dark seeds owe their color, although the cross-cells also contain some pigment granules. This pigment fills the entire cell as a homogeneous brown mass forming a cast of the cell lumen; it is little acted on by reagents.

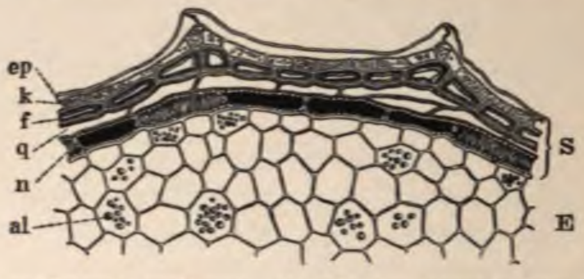


FIG. 235. Poppy (*Papaver somniferum*). Outer Portion of Seed in Cross-section. ×160. (WINTON.)

S spermoderm consists of *ep* epidermis; *k* crystal layer; *f* fiber layer; *q* cross-cells, and *n* netted cells; *E* endosperm, contains *al* aleurone grains.

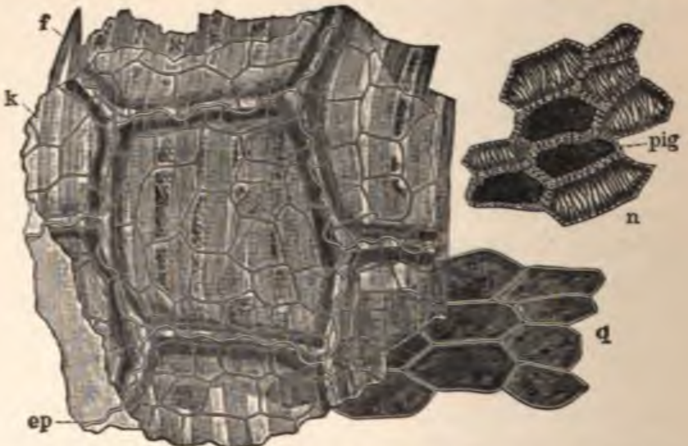


FIG. 236. Poppy Seed. Spermoderm in Surface View. ×160. (WINTON.)

ep epidermis; *k* crystal layer; *f* fiber layer; *q* cross-cells; *n* netted cells containing *pig* pigment.

The blue appearance of the seed, notwithstanding the deep-brown pigment coat, is an interference phenomenon; a colorless but granular medium such as the crystal sand layer appears blue with a dark background such as the pigment layer. After removal of the oxalate sand with hydrochloric acid or filling the interstices of the crystals with a liqiud to counteract the granular condition, the seed coat appears brown.

The **Endosperm** (Fig. 235, *E*) and the **Embryo** consist of delicate parenchyma cells with abundant contents of oil and aleurone grains; the latter in the inner cells are up to 7μ in diameter and contain numerous globoids and small crystalloids.

HEMP CAKE.

This product is found on the market chiefly in eastern Europe. The well-known rounded or broadly ovoid, greenish- or gray-brown, one-loculed, one-seeded fruits (so-called "seeds") of the hemp plant (*Cannabis sativa* L.) are characterized by their high oil content (31–34.5 per cent). In addition to the oil, the embryo, constituting the bulk of the fruit, contains aleurone grains but no starch. Owing to the presence of hulls in the cake, identification is not difficult.

MICROSCOPIC STRUCTURE.[1]

The hull consists of pericarp and spermoderm. The **Pericarp** (Figs. 237, 238, and 239) has outer soft layers and an inner hard layer.

The cells of the **Epicarp** (*ep*) are wavy in outline and have more or less thickened sclerenchymatized walls. Following this are layers of **Spongy Parenchyma** (*hy*), **Brown Cells** (*br*), and **Dwarf Cells** (*w*).

The innermost layer is of remarkable **Palisade Cells** (*pal.*). These are radially elongated and have in the outer part a narrow, much-branched lumen which increases in breadth toward the inner end. The radial or side walls are much folded and contain numerous pores. As noted by TSCHIRCH, the pores, although straight or nearly straight in the inner walls, are so grotesquely branched in the side walls as to present a striking appearance in cross-sections, also in surface view or tangential sections. These palisade cells are the chief identifying elements of hemp cake.

---

[1] BÖHMER: Die Kraftfuttermittel. Berlin, 1903, 388. TSCHIRCH: Realenzyklopädie d. ges. Pharm. 1. Aufl., **2**, 524. TSCHIRCH u. OESTERLE: Anatomischer Atlas. Leipzig, 1900, 57. WINTON: Anatomie des Hanfsamens. Ztschr. Unters. Nahr. Genussm. 1904, **7**, 385. *Idem:* The Anatomy of Certain Oil Seeds with Especial Reference to the Microscopic Examination of Cattle Foods. Conn. Agr. Exp. Sta. Rpt. 1903, 175. *Idem:* Microscopy of Vegetable Foods. New York, 1915, 214. See also bibliography in WINTON.

The tissues of the thin **Spermoderm** (*N*) and **Endosperm** (*E*) as well as of the **Embryo** (*C*) are of lesser importance in diagnosis. Striking cystolith hairs and glandular hairs occur on the calyx, which often envelopes the seed.

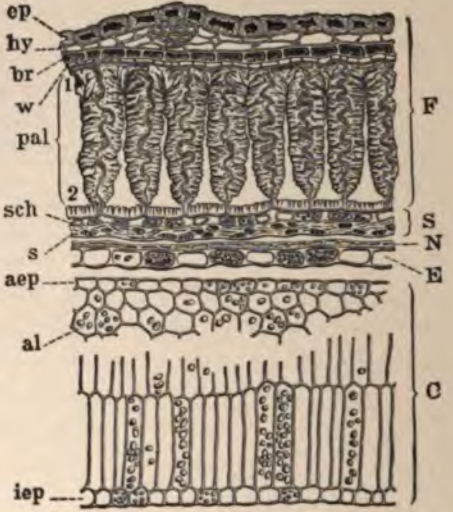


FIG. 237. Hemp Seed (*Cannabis sativa*). Cross-section of Outer Portion of Fruit. ×160. (WINTON.)

F pericarp consists of *ep* epicarp, *hy* hypoderm, *br* brown cells, *w* dwarf cells, and *pal* palisade cells; *S* spermoderm consists of *sch* tube cells and *s* spongy parenchyma; *N* perisperm; *E* endosperm; *C* cotyledon with *aep* outer epidermis, and *iep* inner epidermis, *al* aleurone grains.

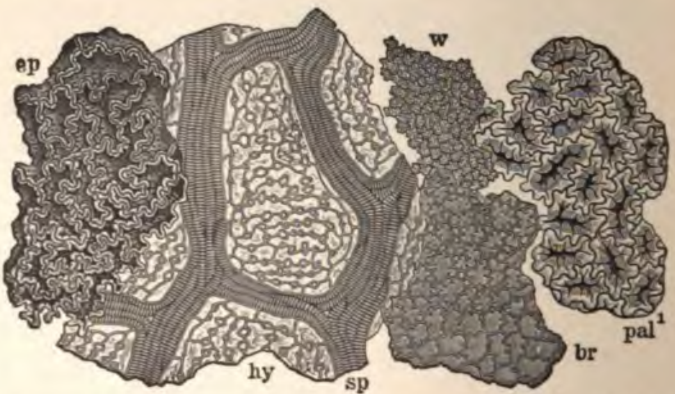


FIG. 238. Hemp. Pericarp in Surface View Seen from Above. ×160. (WINTON.)

ep epicarp; *hy* hypoderm with *sp* spiral vessels; *br* brown cells, *w* colorless cells; *pal*^{1} palisade cells (see Fig. 237).

BEECHNUT CAKE.

The fruit of the red beech (*Fagus silvatica* L.) contains **about** 23 per cent of fatty oil, which usually is expressed after removal of the fruit coat (pericarp). The cake can not be used indiscriminately as a feed, since, according to BÖHM,[1] it contains a poisonous principle, **Cholin,** which, when fed to horses, causes trembling, staggering, madness, and even death, although it has no injurious effects on ruminants and swine. Beechnuts only occasionally reach maturity—on the average once in five years—but when a good crop is secured the cake is placed on the market in considerable quantities and at a very cheap price. Owing to its similarity to the more expensive linseed cake, it is said by KÖNIG to be used as an adulterant of the latter.

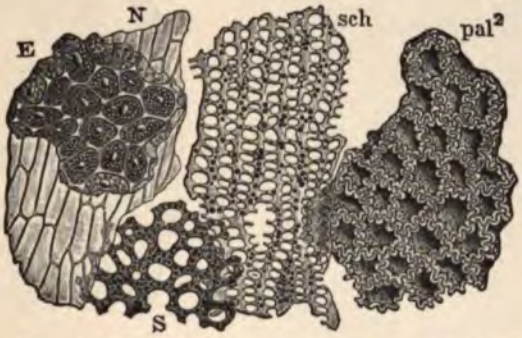


FIG. 239. Hemp. Palisade Cells, Spermoderm, Perisperm, and Endosperm Seen from Within. ×160. (WINTON.)

pal^2 palisade cells (see Fig. 237); *sch* tube cells, and *S* spongy parenchyma of spermoderm; *N* perisperm; *E* endosperm.

MICROSCOPIC STRUCTURE.[2]

The microscopic examination of undecorticated beechnut cake presents no especial difficulties; on the other hand, it is not easy to identify decorticated cake or detect its presence in linseed cake.

In the preparation of the undecorticated product all the tissue elements of the **Pericarp** or shell, including the epicarp and the sclerenchyma plates, are removed. The brown cells of the **Epicarp** in surface view are polygonal (Fig. 240, *B*, *ep*) and in cross-section rounded-quadrate with thickened outer walls (*A*, *ep*). Numerous hairs (*B*, *h*, *h′*, *h″*) occur on the epicarp, especially at the apex of the fruit. About these the epicarp cells often form rosettes.

---

[1] Arch. Exp. Path. u. Pharmakol., **19**, 89.

[2] COLLIN et PERROT: Les résidus industriels. Paris, 1904, 104. T. F. HANAUSEK. Realenzyklopädie d. ges. Pharm. 1. Aufl., **7**, 407. PFISTER: Buchnusskuchen. Landw. Vers. Stat. 1894, **43**, 445.

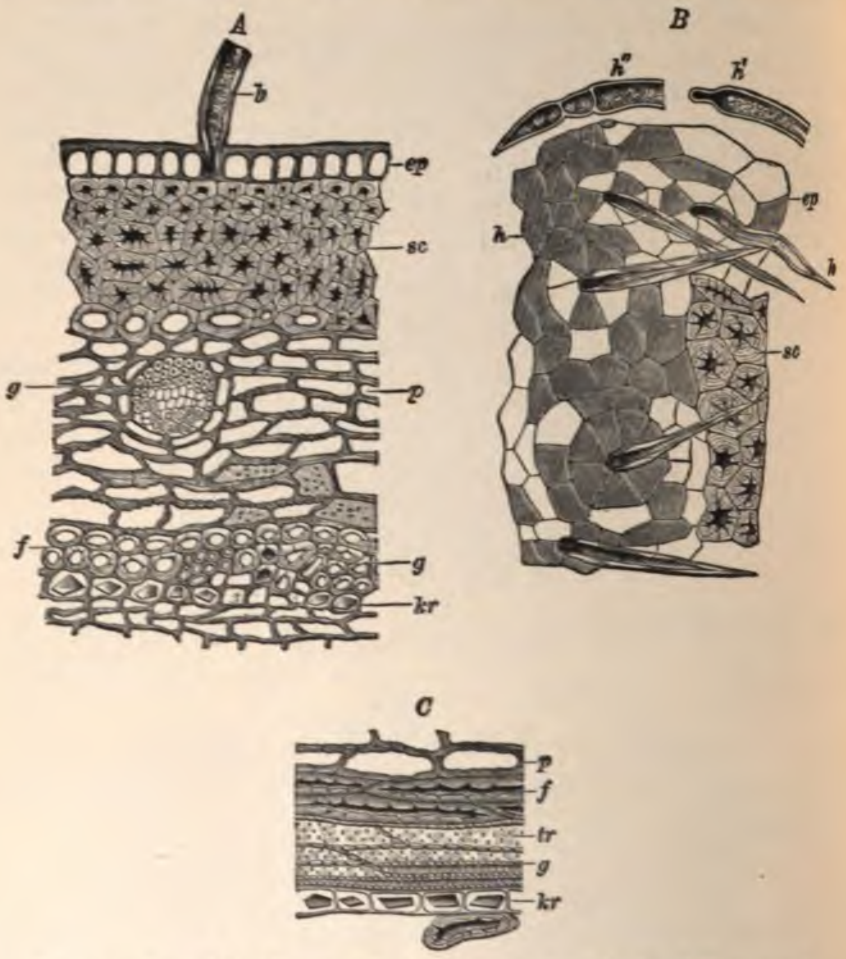


FIG. 240. Beech Nut. (*Fagus silvatica*). Elements of Shell. (T. F. HANAUSEK.)

A cross-section: *ep* epicarp with *h* hair; *sc* sclerenchyma; *p* parenchyma with *g* (above) small vascular bundle, and *g* (below at the right) part of large vascular bundle; *f* bast fibers; *kr* crystals.—*B* surface view: *ep* epicarp with *h* unicellular hair; *h′* hair with constricted base and *h″* multicellular hair; *sc* sclerenchyma.—*C* part of a vascular bundle in longitudinal section: *f* bast fibers; *tr* tracheids; *g* spiral vessels; *kr* crystal fibers.

Beneath the epicarp lies a rather thick sclerenchyma plate (*A* and *B*, *sc*) composed of typical, very strongly thickened, richly porous stone cells. Following the last is a **Parenchyma Layer** which in the cake is easily identified. This parenchyma consists of brown, porous, mostly somewhat tangentially elongated cells, in the outer part with small bundle strands (*A*, *g*), and in the inner layers with broad vascular bundles made up of bast fibers, spiral vessels, tracheids, and crystal fibers (*A*, *C*).

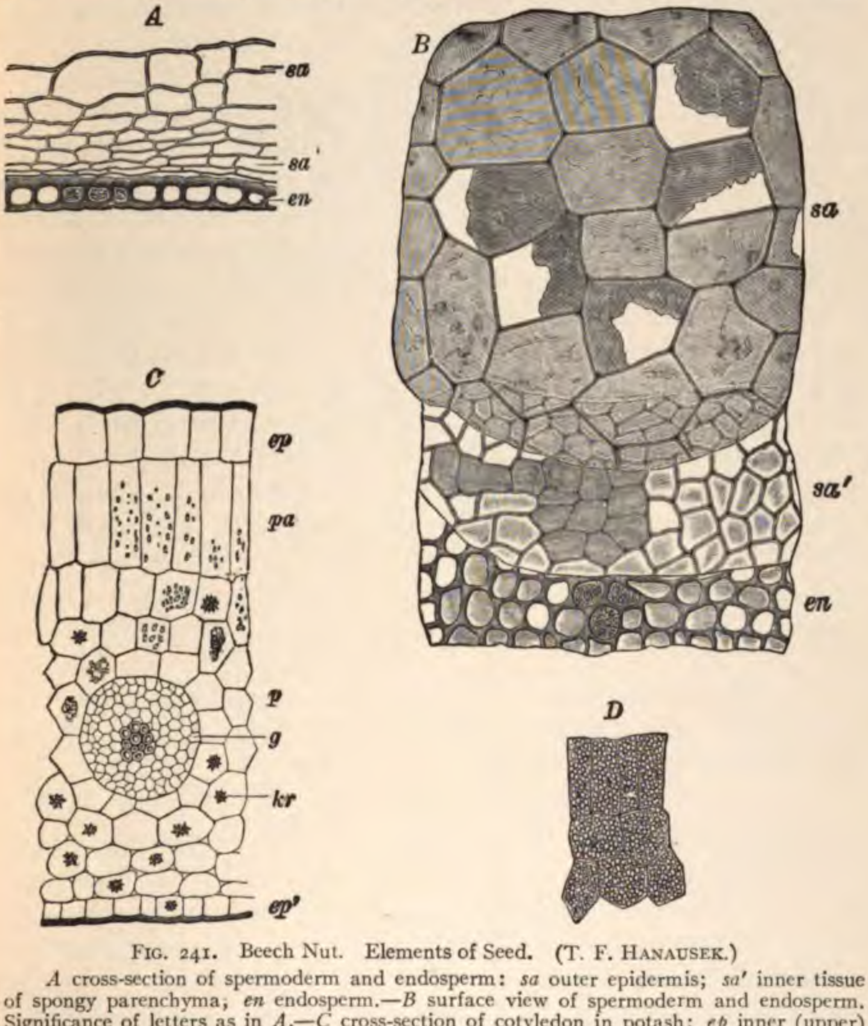


FIG. 241. Beech Nut. Elements of Seed. (T. F. HANAUSEK.)

A cross-section of spermoderm and endosperm: *sa* outer epidermis; *sa'* inner tissue of spongy parenchyma; *en* endosperm.—*B* surface view of spermoderm and endosperm. Significance of letters as in *A*.—*C* cross-section of cotyledon in potash: *ep* inner (upper) epidermis; *pa* palisade parenchyma; *p* polyhedral parenchyma cells with *g* vascular bundle; *kr* crystal rosettes.—*D* parenchyma of cotyledon in water, showing cell contents.

The hairs are valuable diagnostic elements. These are mostly unicellular, seldom multicellular (*B*, h''), thick-walled, with a much-narrowed base (*B*, *K*); a few, however, are thin-walled and spirally twisted like cotton hairs. Since linseed cake is entirely free from hairs, their presence in this product suggests an admixture of beechnut cake. The much-folded cotyledons and the radicle of the seed are covered by a meager endosperm and a spermoderm of very simple structure.

The **Spermoderm** has an **Outer Epidermis** (Fig. 241, *A* and *B*, *sa*) of large, polyhedral, nearly empty brown cells, and a **Middle Layer**, several cells thick, made up of cells similar to but smaller than those of the epidermis. The walls of these cells show peculiar striations, react neither for cellulose nor lignin, but, as their appearance indicates, are very probably suberized. The cells of the outer epidermis especially present the appearance of cork. In some of these, protoplasmic contents are still evident. Toward the inner surface the cells are entirely compressed and form an obliterated spongy tissue (*sr*). Following the last is a single cell layer of thick-walled, colorless cells which swell to a gelatinous mass in potash and remind one of the aleurone cells of the cereals. This layer is all that remains of the **Endosperm** (*A* and *B*, *en*).

The **Cotyledons** are of typical bifacial structure (*C*). Beneath the inner epidermis is a palisade parenchyma (*pa*), which together with the remaining mesophyl tissue is completely filled with oily protoplasm and aleurone grains (*D*). By treatment with potash the contents are largely removed, and there remains in each parenchyma cell a minute crystal cluster (*D*, *kr*).

From the above it appears that the identification of decorticated cake depends to a certain extent on negative proof: other tissues than those described should not be present.

It is especially recommended to compare the sample under examination with standard material—a procedure which in general should never be omitted.

PALM-NUT CAKE.

The cake obtained from the seeds of the oil palms (*Elæis Guineensis* L. and *E. melanococca* Gaertn.) is used both as a feed and an adulterant of ground spices.

The gray-brown to black-brown elongated, ovoid, or bean-shaped seeds present a reticulated appearance, owing to numerous furrows on the surface. The thin spermoderm is united to the kernel, which consists of a very oily, horny endosperm. This latter contains the embryo in a small hollow at the upper end.

MICROSCOPIC STRUCTURE.[1]

Richly pitted, in surface view polygonal, stone cells (Fig. 242, *sc*; Fig. 243, *I*, *sc*) from the **Endocarp** are attached to the outer surface of the spermoderm. The cells of the **Spermoderm** (Figs. 242 and 243, *sa*) in the **Outer Layers** are thin-walled, rounded polyhedral or elongated, almost rod-shaped, with dark-brown homogeneous contents. They are in several layers, those in each layer being parallel, but crossing those in other layers at an angle, thus presenting a very characteristic appearance (Fig. 243, *I*, *sa*). In the **Inner Layers** the cells have contents which become lemon-yellow in potash.

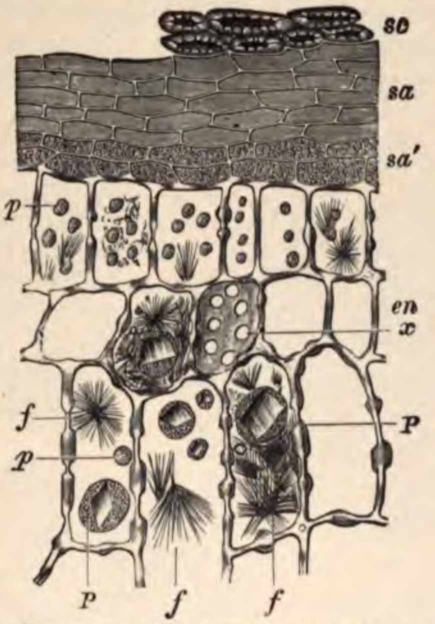


FIG. 242. Palm Nut (*Elæis Guineensis*). Cross-section of Outer Part of Seed after Treatment with Alcoholic Iodine and Dilute Sulphuric Acid. (T. F. HANAUSEK.)

sc adhering sclerenchyma elements of endocarp; *sa* outer layers of spermoderm with homogeneous brown contents; *sa'* inner layer with lighter-colored contents; *en* endosperm showing *x*, a wall with large pores, in surface view; *P* large and *p* small aleurone grains with crystalloids, and *f* needle-shaped crystals of fat in radiating bundles.

---

[1] T. F. HANAUSEK: Ueber die Frucht der Oelpalme. Ztschr. allg. Österr. Apoth. Ver. 1882, 325–328. C. HARTWICH: Chem. Ztg. 1888, 957. HARZ: Samenkunde, **2**, 1124. ARTHUR MEYER: Ueber die Oelpalme. Beiträge zur Kenntniss pharmac. wichtiger Gewächse. Arch. Pharm. 1884, **22**, 19. MOELLER: Mikroskopie der Nahrungs- und Genussmittel. Berlin, 2. Aufl. 1905, 483. VOGL: Die wichtigsten vegetabilischen Nahrungs- und Genussmittel, 550. WINTON: Microscopy of Vegetable Foods. New York, 1915, 290.

The **Endosperm** is made up of rounded prismatic, radially arranged cells, those at the periphery being short, those in the interior up to 80μ long. The cell walls are of cellulose and have 6–8 large circular pits which are highly characteristic of this tissue. Since the cell membranes, except for the pits, are quite thick, the walls at the sides of the cell appear knotty thickened (Fig. 242; Fig. 243, *III*). The contents consist of lumpy, streaked, or finely radiating bundles of fat raphides (*f*), also large and small aleurone grains (*P*, *p*). The peripheral cells contain the small aleurone grains, while each of the others contains one large grain $24–27\mu$ in diameter and several small grains. In alcohol mounts the aleurone grains appear strongly refractive, light yellow, on the surface streaked or finely granular. In oil mounts of the cake many of the cells seem to be free from fat, while others contain numerous raphides of fatty acid and large aleurone grains which are polyhedral in outline and covered with a fine network; the small aleurone grains are mostly sharply angular.

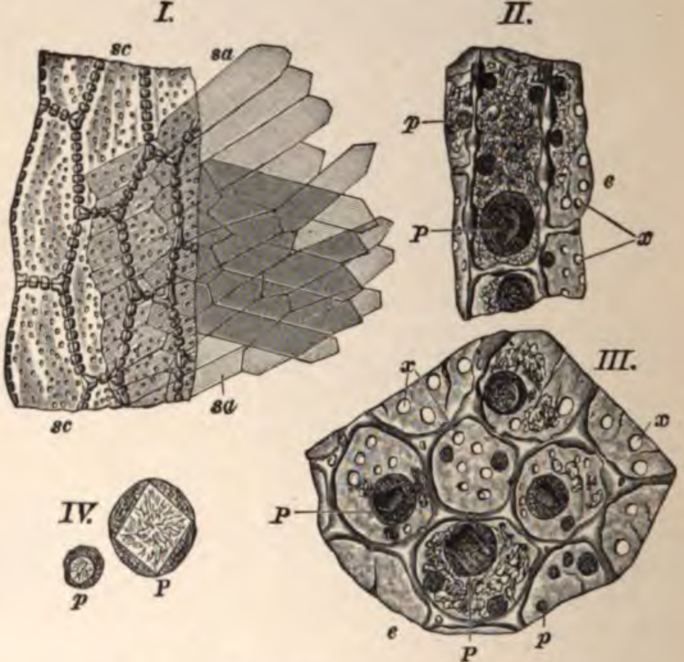


FIG. 243. Palm-nut Meal. (T. F. HANAUSEK.)
I elements of shell: *sc* sclerenchyma of endocarp; *sa* outer cells of spermoderm.—*II* endosperm cells in radial section.—*III* endosperm cells in tangential section: *x* large pores; *p* small aleurone grains, *P* large aleurone grains.—*IV* single aleurone grains: *P* large; *p* small.

If, after extracting the fat with benzine, the mount is laid in iodine glycerine, the aleurone grains absorb the iodine, become golden brown in color, and show clearly the inclosed large rhombohedron-like crystalloid. This latter is rendered especially distinct by staining with tincture of iodine and placing in very dilute hydrochloric acid. After this treatment the golden-yellow aleurone grains show an entirely transparent peripheral ground substance and within this the shining crystalloid (Fig. 243, *IV*, *P*). Chloral hydrate also serves as an excellent clearing agent. After 12–15 hours' standing in this reagent the aleurone grains appear pale yellow and show a finely granular surface.

Palm-nut cake is recognized with ease and certainty by the above-described endosperm cells with circular pits and by the cell contents. Of value in diagnosis are also the parallel-arranged cells of the spermoderm, those in one layer crossing those of another.

COCOANUT CAKE.[1]

Copra (also spelled Coprah, Kopra, and Copperah), the dried seeds of the cocoanut palm (*Cocos nucifera* L.), is a valuable raw material for the manufacture of oil. In countries where the cocoanut is grown the fat is commonly obtained by pressing, less often by boiling the seed in water. Cocoanut cake, the residue from the presses, is brought into Europe (England, France, Germany) from various tropical regions, chiefly Ceylon, and is there purified and pressed, or else extracted with carbon bisulphide. The color of the cake is light brown or reddish white. Accidental impurities are seldom present, although occasionally fraudulent materials are added. The product has a high digestibility and nutritive value.

The globular seed, freed from the hard shell or endocarp, is brown or reddish brown, with a much-veined outer surface due to the vascular bundles or their impressions. The reverse of this system of venation is found on the inner surface of the shell. A complete separation of the closely united pericarp and seed is impossible, part of the endocarp tissues always being found on the outer surface of the spermoderm. The latter is brown in color and is firmly attached to the white, oily, cartilaginous, hollow kernel. This endosperm, on the fractured surface, shows a radially fibrous structure. Cocoanut milk is found in the cavity of the fresh nut, but dries up on long standing.

---

[1] L. GEBEK: Ueber Cocosnusskuchen und Cocosnussmehl. **Landw. Vers.** Stat. 1894, **43**, 427–440.

MICROSCOPIC STRUCTURE.[1]

Gray-brown scales may be easily separated from the outer surface of the dried seed. These consist of almost colorless, variously shaped, sclerenchymatized, and richly pitted cells (Fig. 244, *A*, *sc*), which also occur on the inner surface of the shell. Isolated groups of these cells occur between the tissues of the true spermoderm, from which they are readily distinguished by the red color obtained with phloroglucin-hydrochloric acid, showing the lignified character of the walls.

The **Spermoderm** proper consists of three layers, of which the first two are not sharply separated. The cells of the **Outer Layers** are elongated, in surface view mostly rectangular, less often bent, and united in groups of two to four or more cells, those in different groups and different layers being extended in different directions. Further inward the cells become shorter, are rounded or rounded-polygonal, and when dry are compressed with folded walls. The contents consist of a brown material in lumps. After warming in potash the cell walls are swollen, pitted, and have the contents deposited on the walls, leaving the middle of the cell empty (Fig. 244, *B* and *C*). These holes in the cell contents when round appear like large pores. In some of the cells the contents form dark-brown globular drops or grains. The vascular bundles, found in the outer part of the spermoderm, consist largely of spiral vessels.

The **Inner Layer**, appearing in cross-section as a narrow, dark band, is one, or less often two, cells thick and consists of somewhat elongated cells with strongly thickened walls.

The **Endosperm** begins with a layer of nearly isodiametric cells with cuticularized outer walls. The remainder of the endosperm cells are radially arranged, five- to six-sided, very thin-walled prisms, 160–300μ long and 40–60μ broad (*A*, *en*). To these prisms is due the fibrous structure of the kernel. Sections mounted in oil show wrinkled folded walls (*D*); after treatment with alkali or warming in water the walls straighten out, and large but very delicate pits, which, however, are lacking on the longitudinal walls, are evident (*E*, *pt*). With iodine and

---

[1] [illegible] Die [illegible]. Berlin [illegible]. Collin et Perrot: Les résidus industriels. Paris 1904, [illegible]. T. F. Hanausek: Realencyklopädie d. ges. Pharm. 2. Aufl., [illegible]. [illegible] Wiesner's Rohstoffe des Pflanzenreiches, 2. Aufl. 2, [illegible]. Winton: The Anatomy of the Fruit of Cocos nucifera. Amer. Jour. Sci. [illegible], 12, [illegible]. Conn. Agr. Exp. Sta. Rep. [illegible] and Amer. Jour. Pharm. [illegible], 73, [illegible]. Winton: Microscopy of Vegetable Foods. New York [illegible].

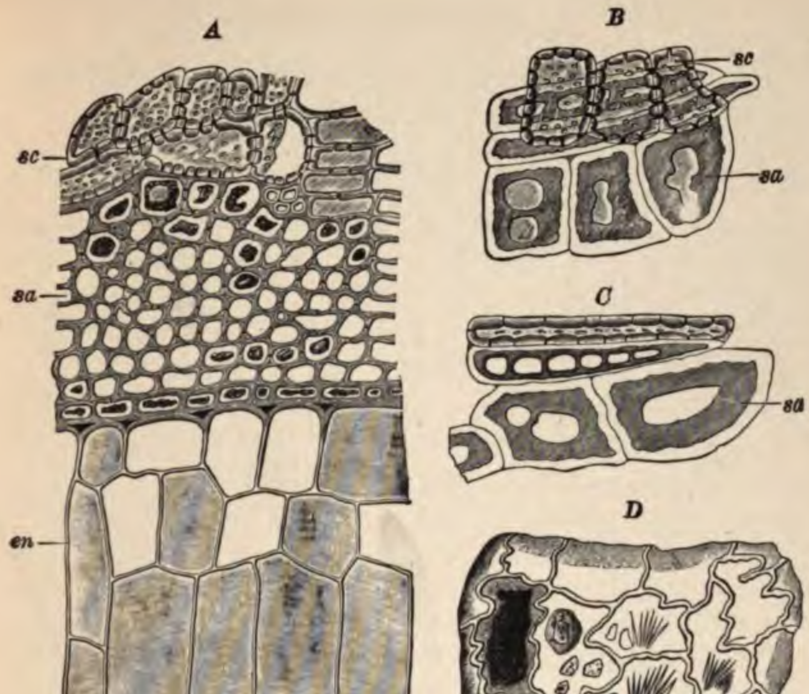


FIG. 244. Cocoanut (*Cocos nucifera*). Elements of Seed. (T. F. HANAUSEK.)

A cross-section: *sc* sclerenchyma cells of endocarp; *sa* spermoderm; *en* endosperm, showing cells, but no contents.—*B* and *C* outer elements in surface view: *sc* sclerenchyma cells, *sa* spermoderm.—*D* tangential section of endosperm cells in oil.—*E* same as last after swelling, showing two of the cells with round pits (*po*).—*F* endosperm cells in glycerine: *ei* oily protoplasm; *al* aleurone grain; *fk* needle-shaped fat crystals; *kr* crystalloids.—*G* endosperm cells in iodine and sulphuric acid: *cel* folds of cellulose; *al* aleurone grains with *kr* crystalloids.—*H* isolated aleurone grains in Millon's reagent.

sulphuric acid the cell walls become blue and show very characteristic, diagonal-spiral striations (*G*).

Glycerine mounts (*F*) are suited for studying the cell contents, which consist of large lumps of oily protoplasm (*ei*), aleurone grains (*al*), bundles of fat raphides (*jk*), and large and small crystalloids (*kr*). After treatment with iodine and very dilute sulphuric acid the large crystalloids of the aleurone grains are evident. These aleurone grains may be found free in mounts prepared from the cake, and their crystalloid contents may be brought out clearly by treatment with Millon's reagent. Starch is entirely absent.

MISCELLANEOUS OIL CAKES.

Oil cakes of value as cattle feeds are obtained from maize germs, which are separated from the starchy matter in the manufacture of maize flour and glucose, almond kernels, walnuts, candlenuts (*Aleurites triloba* Forst), and other oil seeds and nuts.[1] The residues from the manufacture of essential oils from umbelliferous fruits (anise, caraway, fennel, coriander) [2] are utilized as cattle foods. Castor pomace,[3] the cake from the manufacture of castor oil, because of the presence of a poisonous substance, ricin, can not be used for feeding, but is employed as a nitrogenous fertilizer.

MYROBALANS.

For the purpose of studying a fruit used as a tannin material, we have selected myrobalans, the fruit of ***Terminalia Chebula*** Retz. (order *Combretaceæ*), a tree growing throughout India proper to the foot of the Himalayas, in further India, Ceylon, and other islands of the East Indies. Common myrobalans are the dried ripe drupes, black or Indian myrobalans are the unripe fruits of the same tree without seeds and almost without stones.

The fruits [4] are elongated, irregularly ovoid, usually narrowed toward cells are polygonal with sharp angles, and uniform in size. Fragments of this tissue occur in abundance in the powder.

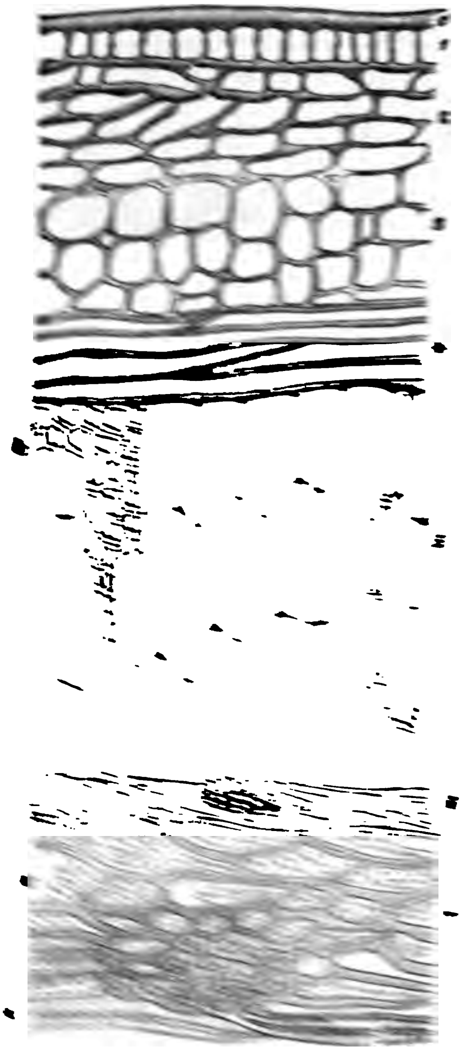
---

[1] Böhmer: Kraftfuttermittel. Berlin, 1903. Collin et Perrot: Les résidus industriels. Paris, 1904. König: Untersuchung landwirtschaftlich und gewerblich wichtiger Stoffe. Leipzig, 3. Aufl. 1906. Moeller: Mikroskopie der Nahrungs- und Genussmittel. Berlin, 2. Aufl. 1905. Winton: Microscopy of Vegetable Foods. New York, 1915.

[2] See the works named above, also Uhlitzsch: Rückstände der Fabrikation ätherischer Oele. Landw. Vers. Stat. 1893, **42**, 215.

[3] See the works named above, also Collin: Tourteau de ricin; ses dangers, ses caractères anatomiques. Jour. pharm. chim. 1903.

[4] The name "myrobalan" is derived from μύρον (myron=balsam, salve) and βαλανος (balanos=acorn, nut). Five species were known to the ancients.



[illegible]

[illegible]

[illegible]

tangentially elongated, in surface view rounded, and become blue with chlorzinc iodine. The collenchyma passes into a loose **Parenchyma** with rounded cells containing small starch grains (Fig. 245, *3*).

Transversely arranged **Sclerenchyma Fibers** with strikingly parallel walls form a girdle about the fruit. Adjoining the inner part of the last layer are strands of radially, or more often longitudinally, extended sclerenchyma fibers (*b*), occurring at short intervals in a parenchymatous ground tissue. These strands either diminish in thickness from without inward and suddenly disappear or else form, as it were, bridges through the outer mesocarp to the vascular bundles in the inner layers. Slender strands of radially arranged, thickened, but non-prosenchymatous, fibers are of not infrequent occurrence. The presence of longitudinally arranged fibers adjoining the outer sclerenchyma girdle gives strength to the tissues.

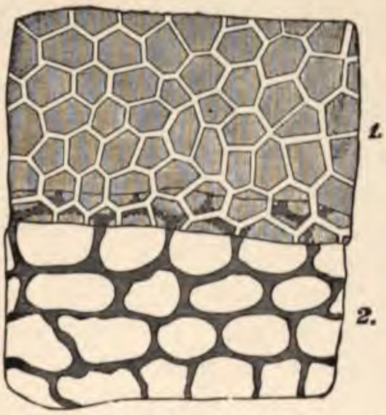


FIG. 246. Myrobalans. Epidermis (*1*) and Collenchyma (*2*) in Surface View. (T. F. HANAUSEK.)

The **Parenchyma** forming the ground tissue (*5*) consists of large cells, in cross-section radially elongated, in tangential section rounded, with intercellular spaces. Potash stretches the walls and causes them to appear very thin. In these large parenchyma cells is stored the tannin. Examined in glycerine they are seen to be entirely filled with a yellow, structureless, but fissured, mass which dissolves in warm water and gives with ferric chloride the tannin reaction. The masses also dissolve completely in potash to a brown liquid, but in hydrochloric acid remain for a time undissolved in the form of yellow flakes. In addition to the sclerenchyma tissues above described, there are also present in this layer groups of variously formed, lignified, and richly pitted cells. It should further be noted that the nearer the cells are to the endocarp the greater is their tendency to form sclerenchymatized walls.

The **Inner Layer** of the mesocarp (Fig. 245, *6*) consists of compressed cells with small vascular bundles.

The **Endocarp** begins with a layer of lignified pitted cells (*7*, *sc*) such as occur in the mesocarp. Because of the numerous pits the surfaces of the cell walls appear like sieves. The larger part of the endocarp, however, consists of true sclerenchyma fibers characterized by their greatly thickened, richly porous, and strongly lignified walls (*7*, *sc'*). They are extended in various directions so that various views of them are obtained in cross-section. Here and there small groups of the broad pitted cells above described occur among the fibers.

In this fiber layer occur also the rounded secretion cavities designated by BRANDIS[1] " gum passages ". They are adjoined by both the ends and longitudinal surfaces of sclerenchyma fibers and have for their immediate boundary a thin membrane. A. VOGL[2] designates these cavities " giant cells " and states that the thin membrane gives with chlorzinc iodine the cellulose reaction. It is a remarkable fact that the ends of the sclerenchyma fibers adjoining them are sometimes disorganized.

The **Inner Lining** of the pericarp is a skin which in surface view is seen to consist of elongated, four-sided, thin-walled, non-lignified cells.

The **Spermoderm** consists of four (or five?) layers. The cells of the **Outer Epidermis** are collapsed and flat. They swell greatly in potash and in cross-section are almost quadrate, with somewhat rounded, very thin outer walls. Under the last lies what appears to be an interrupted layer of tangentially elongated cells with round or slit-shaped pits, giving the wall a reticulated appearance. The next layer is a light-yellow zone of entirely obliterated cells which contains the much-expanded vascular bundles with numerous spiral vessels. Then follows a layer of cells containing a brown pigment. Within the last is what appears in section as a yellow band consisting of obliterated cells. The layer of typical aleurone cells which follows is probably **Endosperm**.

The thin **Cotyledons** contain in their rounded, polyhedral, very thin-walled cells aleurone grains, oily protoplasm, and here and there a large oxalate rosette.

EXAMINATION OF THE POWDER.

The methods described under oil cakes (p. 359) are employed. As a preliminary test the powder is treated with ferric-chloride solution and potash; the first colors the powder dark blue, the latter yellow-brown, owing to the solution of the contents. The fragments of the stone constitute the bulk of the powder. Some of the short sclerenchyma fibers resemble greatly those of olive stones; they are, however, colored brown by potash. Very characteristic also are the variously shaped, strongly pitted, lignified cells of the mesocarp and the outer endocarp. In addition the powder contains numerous pieces of the mesocarp parenchyma with adhering sclerenchyma fibers having characteristic parallel walls. Fragments of the spiral vessels and the epicarp are of not infrequent occurrence. On many pieces of the endocarp we note a concavity belonging to a giant cell (or secretion cavity). Pieces of the seed are very seldom found.

---

[1] *Loc. cit.* 115.

[2] *Loc. cit.* 160.

IVORY NUT OR VEGETABLE IVORY.

Under the above names are known the bony seeds of several palms, which, because of their toughness, hardness, and homogeneous structure, are admirably suited for the manufacture of buttons and various other turned articles. The waste after grinding is utilized as an adulterant of ground spices, etc. As the technical microscopist is often called upon to identify bony substances, he must be acquainted with the various raw materials of this class and their substitutes.

Two kinds of ivory nut are at present on the market, the true and the Polynesian. True ivory nuts are obtained from South American ivory palms of the genus *Phytelephas*, of which *P. macrocarpa* Ruiz et Pavon and *P. microcarpa* Ruiz et Pavon yield the larger part of the commercial product.[1] The Polynesian ivory nut is described further on.

As found in commerce the seed of *Phytelephas* is commonly inclosed in the shell consisting of the inner pericarp, which is 0.4–1 mm. thick, hard, very brittle, light gray on the surface and black within. The seed itself is covered by, and firmly attached to, a brown, scaly spermoderm with a network of vascular bundles and has a broad flat hilum and at one side of this a distinct conical wart covering the embryo. By far the larger part of the kernel is made up of the white, very hard endosperm. The minute embryo is situated in a small hollow in the endosperm, beneath the wart-like elevation mentioned above.

The large Colon and Guayaquil ivory nuts often have, in their interior, clefts and fissures, while the smaller Savanilla and Tumacos species are solid throughout.

---

[1] For descriptions of other species see WIESNER: Die Rohstoffe des Pflanzenreiches. Leipzig, 2. Aufl. 1903, 2.

MICROSCOPIC STRUCTURE.

The **Pericarp** consists chiefly of long, radially arranged **Palisade Cells**, the lumen of which is filled with a siliceous body.[1] Following this is a light-yellow zone of collapsed cells and a layer of small stone cells. After separating the seed from the shell, there remains attached to the latter part of the outer layer of the **Spermoderm**, consisting of **Sclerenchyma Fibers** crossing one another in different directions. The inner spermoderm consists of large, nearly isodiometric, thick-walled, non-porous cells.

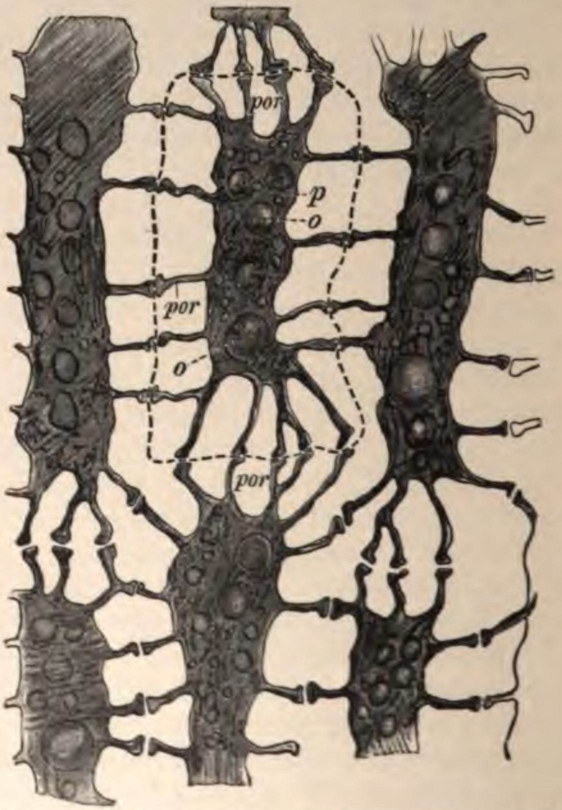


FIG. 247. Ivory Nut or Vegetable Ivory (*Phytelephas macrocarpa*). Cells of Endosperm. (TSCHIRCH.)

por pits, the contents destroyed by warming in water; *o* fat drops; *p* protoplasm.

---

[1] A full description is given by MOLISCH: Die Kieselzellen in der Steinschale der Steinnuss. Centorg. Warenk. Tech. 1891, 103–105.

The cells of the **Endosperm** (Fig. 247) furnish an excellent example of a special form of reserve material. The outer cell layer consists of small rounded thick-walled parenchyma cells. Proceeding inward the cells increase in size, the length reaching over 250μ and the breadth 102μ, while their walls are so strongly thickened that the lumen is only $38–60.8\mu$ broad. This thickened cell wall consists of **Reserve Cellulose** (see p. 54). After treatment with chlorzinc iodine the whole tissue becomes blue-violet. The cells are so fused together that their outlines are not evident, either in longitudinal or cross-section, until after treatment with potash, when they become quite distinct (Fig. 248). The structure of the pits is remarkable. Pore canals perpendicular to the surface penetrate the cell walls as far as the middle lamella, where they enlarge slightly, forming globular cavities (*p*). Corresponding to each of these canals is another in the neighboring cells, the globular cavities of the two being separated by the middle lamella. F. G. Kohl [1] has shown that the contents of the individual cells are united by delicate protoplasmic threads. As solitary threads they penetrate the thickened (non-pitted) parts of the wall and as bundles or aggregate threads they pass through the membrane of the pits and show there peculiar groups, reminding one of the spindle-shaped aggregates of threads formed in the division of cell nuclei.

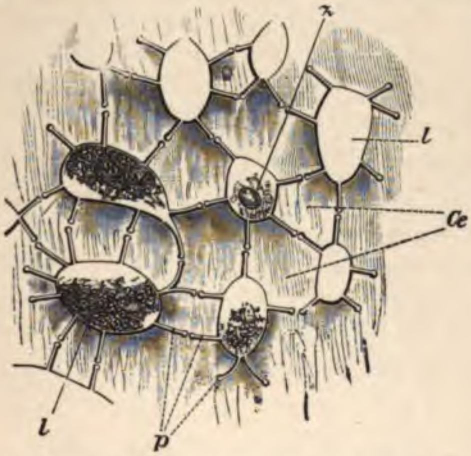


FIG. 248. Ivory Nut or Vegetable Ivory. Endosperm in Cross-section. (T. F. HANAUSEK.) *Ce* cellulose walls; *p* pore canal; *l* lumen; *z* cell nucleus.

Except for the protoplasmic matter and small amounts of fat, no noticeable contents are present in the cells. Crystals are entirely absent.

---

[1] Ber. Deutsch. Bot. Gesell. 1900, **18**, 364.

After warming in water, the protoplasm forms a finely granular mass in which are large drops of fat (Fig. 247, *o*, *p*).

POLYNESIAN IVORY NUT.

In addition to true ivory nuts the seeds of two Polynesian palms come into commerce under the names Tahiti, Fiji, and Salomon nuts and Australian water nuts. According to DINGLER[1] and O. WARBURG,[2] *Cœlococcus Carolinensis* Dingl. yields so-called Carolina nuts and *C. Salomonensis* Warb. Salomon nuts. Both species have the form and size of an apple. The Carolina nut (formerly known as the Tahiti nut) is smooth on the surface, lustrous or finely and thickly striate, brownish black; the Salomon nut is dark red-brown, dull and provided with three meridionally arranged blunt ridges. WENDLAND[3] describes the Carolina nut as follows: The seeds have "a flattened spherical, somewhat oblique form and are flattened or even depressed in the place below the apex where is located the embryo cavity. They are 5–6 cm. high and have a diameter of 6–8 cm. The largest weigh 220–240 grams. Because of the raphe, which extends from the base into the interior of the seed, where it also broadens, the albumen (endosperm) in vertical section is horseshoe shaped." The Salomon nut (recognized by the ribs) has a much narrower chalaza opening and a narrow sunken depression above the embryo.

MICROSCOPIC STRUCTURE.[4]

The microscopic structure of these ivory nuts resembles that of the genuine. Again we find elongated cells with strongly thickened cellulose walls and distinct pore canals with bulbous ends (Fig. 249). Nevertheless small fragments of the Polynesian and true ivory nuts are easily distinguished from one another. The cells of the former compared with those of the latter are narrower and longer; the pits are shorter and somewhat broader, and the lumen is smaller. Following are the transverse diameters of the cells, measured from the pit membranes, also those of the cell lumens.

---

[1] Ueber eine von den Carolinen stammende Coelococcus-Frucht. Bot. Centb. 1887, **32**, 347.

[2] Ueber Verbreitung, Systematik und Verwerthung der polynesischen Steinnusspalmen. Ber. Deutsch. Bot. Gesell. 1896, **14**, 133.

[3] Beiträge zur Kenntniss der Palmen. Bot. Ztg. 1878, **36**, 114.

[4] T. F. HANAUSEK: Ztschr. allg. Österr. Apoth. Ver. 1880, **13**, 360. *Idem:* Zur Anatomie der Tahitinuss. Ztschr. Nahr. Unters. Hyg. 1893, **7**, 197. *Idem:* Realenzyklopädie d. ges. Pharm. 2. Aufl. **11**, 565.

	True Ivory Nut (*Phytelephas*).	Polynesian Ivory Nut (*Cælococcus*).
Transverse diameter of cell.	83–102μ	28–48μ
" " " lumen.	38–60.8μ	19–32μ

These marked differences in diameter, which are also brought out in Figs. 248 and 249, are very valuable in diagnosis.

Another difference lies in the distinctness of the cell contour. Although in the seeds of *Phytelephas* the cell wall shows in water no middle lamella, in *Cælococcus* it is distinct in many places. Mention should also be made of the fact that in *Cælococcus* the membrane, that is, the double cellulose wall, shows throughout narrow, parallel, somewhat twisted, apparently empty clefts which, compared with the long axis of the cell, are oblique (Fig. 250, *Sp*). These clefts do not penetrate the inner membrane adjoining the lumen. The cause of this phenomenon is unknown; possibly it is due to drying or else has some connection with the occurrence of proteid matter in the cellulose membrane or with the protoplasmic threads discovered by Kohl. In *Phytelephas* these clefts are less distinct.

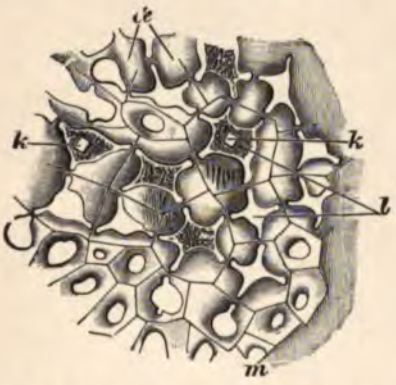


FIG. 249. Polynesian Ivory Nut (*Cælococcus Carolinensis*). Endosperm in Cross-section. (T. F. Hanausek.)
Ce cell wall; *l* lumen; *k* oxalate crystals; *m* middle lamella.

The third important difference between the kinds of ivory nut is the presence of crystals of calcium oxalate in *Cælococcus* and their absence in *Phytelephas*. Almost every cell of the former contains, usually toward one of the narrow ends, a small prismatic crystal (110) belonging perhaps to the tetragonal system (Figs. 249 and 250, *k*). Hydrochloric an sulphuric acids cause the crystals to disappear, although with the latter acid there is no formation of gypsum needles. If, however, the section is previously boiled in alcohol and then in water, the crystals dissolve in sulphuric acid and gypsum needles begin to form immediately. This failure to form needles without the preliminary treatment with hot alcohol and water may be explained as due to the presence of a fatty or gelatinous mass about each crystal which hinders the crystallization of the newly formed calcium sulphate. The occurrence of calcium oxalate crystals in a seed with reserve material in the form of hydro-cellulose, not fat and starch, is a very rare phenomenon.

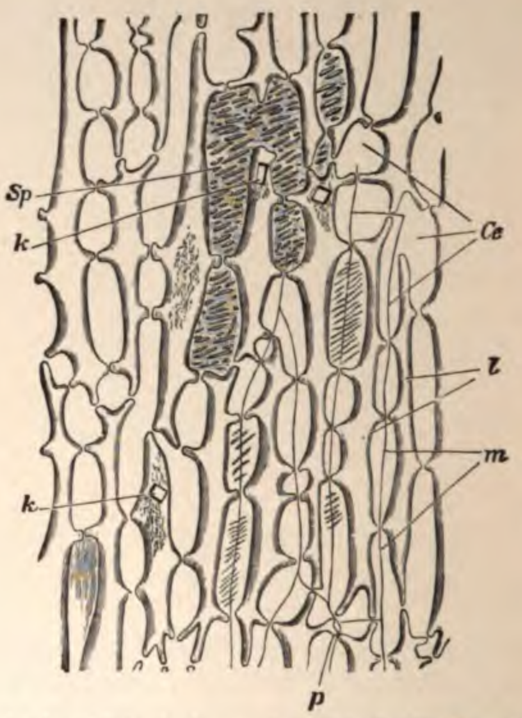


FIG. 250. Polynesian Ivory Nut. Endosperm in Longitudinal Section. (T. F. HANAUSEK.)
Ce cell membrane; *m* middle lamella; *p* pit; *l* lumen; *k* crystals; *Sp* diagonal clefts in the cell membrane.

Polynesian ivory nuts have a yellowish endosperm, whereas the endosperm of true ivory nut is usually bluish white. Now and then (e.g., in the year 1895) the quality of the Polynesian nuts is abnormally poor.

Probably this is due to the collection of old nuts which have lain in the mud, where they have begun to sprout thus softening the endosperm.

The seeds of many other species of palm (e.g., date palm [1]) have the reserve material stored in the endosperm in the form of cellulose; most of these, however, are of no commercial importance.

---

[1] For descriptions of the anatomy of the date-stone see T. F. HANAUSEK: Chem. Ztg. 1886, **10**, 701. MOELLER: Mikroskopie der Nahrungs- und Genussmittel. Berlin, 2. Aufl. 1905, 484. WINTON: Microscopy of Vegetable Foods. New York, 1915, 390.

CHAPTER VIII.

TEETH, BONE, HORN, ETC.

I. True Bones.

THE bones of various mammals, especially the ruminants, are extensively used in the arts. From bones are prepared animal charcoal (valuable because of its absorptive properties), bone ash, i.e., bones burned to a white ash (a raw material used for the manufacture of phosphoric acid and as a fertilizer), and glue. Many useful articles, such as buttons and knife-handles, are made from the untreated bones, and it is these which are subjects for microscopic examination. We will consider here somewhat briefly the external and internal structure of bones so far as this is of importance to the technical microscopist.

As regards their chemical composition, bones, after removal of adhering tissues, fat, and moisture, consist of inorganic constituents and one organic substance, namely, **Ossein**. The inorganic constituents are lime, phosphoric acid, carbonic acid, and very small amounts of magnesia and fluorine. Just how these elements are combined in the bones themselves is not certainly known; bone ash, however, contains 83–84 per cent of tricalcium phosphate, 9 per cent of calcium carbonate, 2–3 per cent of magnesium phosphate, 4 per cent of calcium fluoride, and traces of calcium sulphate. Ossein, which makes up 35–37 per cent of bones, is converted by long boiling into glue; to this constituent bones owe a certain small degree of elasticity. The long tubular bones of the legs are especially suited for technical purposes. Each of these consists of a tubular middle part (**Diaphysis**) and two terminal joints (**Epiphyses**) with cartilaginous exterior. The hollow of the middle part is filled with marrow (connective tissue and fat) and blood vessels. The joints are not hollow.

Three distinct parts may be distinguished macroscopically in the bony mass, namely, a compact substance, a spongy tissue, and a cellular tissue. The compact substance makes up the outer part of the bone. It is homogeneous, without large cavities, and takes an excellent polish. It is most strongly developed on the diaphysis, for which reason this part is best suited for technical purposes. Toward the interior this compact substance passes into a spongy tissue consisting of many scales, arranged in different directions, between which are numerous gaps and cavities. The cellular tissue is developed to a remarkable degree in the epiphyses. It should here be noted that the distinction between spongy and cellular tissues is only relative and both may be consolidated into one tissue. In the end parts of tubular bones the scales and bars forming the cellular tissue are arranged so as to resist best the strain and pressure to which the bones are subjected during the movement of the whole body and the performance of work. They act, as it were, as elastic columns and rafters arranged in conformity to the laws of statics and mechanics.

Even with low magnification it may be seen that the compact bony substance is penetrated by fine canals containing blood vessels. These are **Havers' Canals**, so-called in honor of their discoverer, CLOPTON HAVERS, an English anatomist of the seventeenth century. For the most part they run parallel to the longitudinal axis of the bone, but they anastomose with one another by means of cross-canals and on both the outer and inner surfaces of tubular bones have outlets in the form of narrow openings (Fig. 251, *h*).

For microscopic examination we prepare a cross-section of the bone either by cutting or by grinding on a stone (see p. 20), treat with dilute hydrochloric acid in order to remove the inorganic matter, wash and mount in water. We find now that each Havers' canal—appearing in cross-section as a circle—is surrounded by a thin structureless lamella of ossein. Several of these canals with their lamellar membranes are together encased in a system of concentric sheaths, and all these groups are in turn surrounded by several larger outer lamellæ corresponding in size with the outer circumference of the bone. From this it is evident that bones have a laminated structure; this structure is a characteristic of true bones. Dentine teeth, since they show no laminations, are not to be classed with true bones. Because of this structure bones, after gradual weathering, have a scaly surface and burned tubular bones often show concentric cracks.

We will now examine in water a cross-section prepared by grinding but not otherwise treated (Fig. 251, *I*). If facilities for grinding a section are not at hand, or if it is desired to make a rapid examination, a section—naturally not a very thin section—may be cut with a good scalpel, treated with dilute hydrochloric acid until a distinct evolution of gas is evident, washed quickly in water, and, after removing the water with a filter, mounted in glycerine with gentle heating. By this treatment the section is usually sufficiently cleared to show the following characteristics. We see great numbers of very small black—owing to inclosed air—elongated spindle-shaped cavities with pointed ends and proceeding from these many fine, branching canals which either unite with one another or open into the Havers' canals. Longitudinal sections show that these minute canals as a rule run at right angles to the longitudinal axis of the bone and parallel to one another (Fig. 251, *II*). The student of applied vegetable histology will observe the close resemblance of these formations to porous stone cells. They are designated by the somewhat inappropriate name "**Bone Corpuscles**", although in dead bones, as we have seen, they are empty cavities; a more suitable name would be "**Bone Cells**". By these characteristic elements we are able to identify the smallest fragment of a bone.

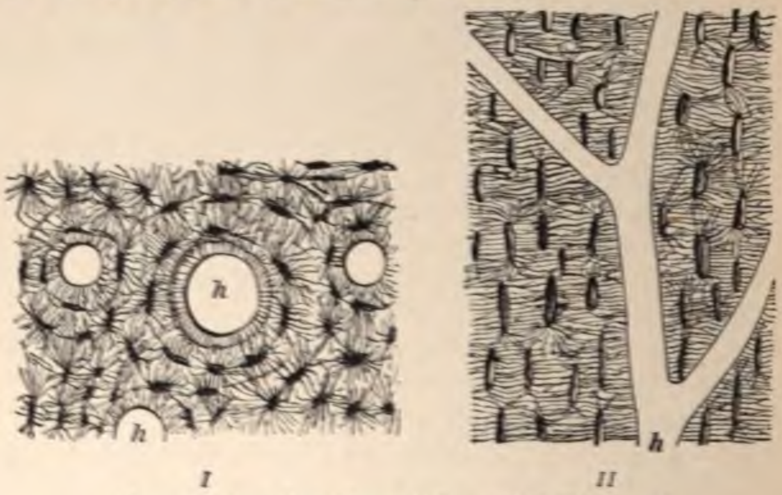


FIG. 251. Bone from Femur of Ox. (T. F. HANAUSEK.)
I cross-section; *II* longitudinal section; *h* Havers' canal.

Bone tissue, as its microscopic structure and physiological function teach, forms a special modification of the connective tissue which occurs in many forms in animal bodies. We find in living bone substance naked spindle-shaped protoplasmic lumps, that is, naked bone cells which inclose an elongated or round core and occur in each of the hollow cavities above described. These cavities are the enlarged intersection points (lacunæ) of a highly delicate network of lime passages penetrating the intercellular mass of the bone tissue. In dead bones these true bone cells are no longer evident; there remain only the cavities with the minute passages.

DEER ANTLERS have the same structure as true bones.

II. Teeth.

Teeth are divided into two classes according to the composition of the chief constituent: **Dentine Teeth**, or teeth bones, and **Horn Teeth.** Dentine teeth in many cases also have a tissue related to horn, the enamel, the chief organic constituent of which consists of a horny substance not of connective tissue, yielding glue.

Dentine teeth are in turn divided, according to their development and morphological characters, into two groups. Those of the first group, known as **Root Teeth** or **Closed Teeth**, cease to grow after a certain time; they have true roots, that is, roots which are more or less pointed and are closed except for a very small opening. Teeth of the second group, the so-called **Rootless Teeth**, or **Open Teeth**, are limited as to growth only by the life of the animal; instead of roots they have a thin-walled base with a large open cavity.

A closed tooth is made up of (1) the **Crown**, or visible part, (2) the **Neck**, or that part inclosed by the gum (gingiva), and (3) the **Root**, that part which is wedged in between the walls of the jaw cavity (alveolus). The main part of the tooth, consisting of the dentine (ivory), is hollow within and contains a soft mass rich in nerves, known as the **Pulp.** The dentine of the crown is covered by a very hard coating, the so-called **Enamel**, while the dentine of the root is surrounded by a material known as **Tooth Cement**, which has the structure of true bone, with evident cavities and, very rarely, Havers' canals.

Dentine is chemically identical with bone, but anatomically is very different. It consists of a ground substance in which are very fine canals (**Dentine Canals**). The ground substance itself very often shows a definite structure, being made up of uniform-sized globules (**Globuli**). It is obvious that between these globules there must be spaces; these are known as **Interglobular Spaces**. There are then in the dentine two kinds of cavities: the dentine canals and the interglobular spaces.

The **Enamel** is made up of six-sided prismatic fibers arranged at right angles to the crown. These fibers are very firmly joined together, imbedded in a horny ground mass, and covered on the free surface by a thin membrane.

Now that we have considered the general structure of normal teeth, we will take up those used for technical purposes.[1] Usually these are known under the general name of ivory, although all of them are not the teeth or tusks of elephants.

The ivory of commerce is obtained from one extinct species, namely, the mammoth (*Elephas primigenius*), and six living species, namely, the Indian and African elephants (*Elephas Indicus*, *E. Africanus*), the hippopotamus (*Hippopotamus amphibius*), the walrus (*Trichechus Rosmarus*), the sperm whale (*Physeter macrocephalus*), and the narwhal (*Monodon monoceros*).

TRUE IVORY.

The tusks of the elephant and mammoth yield true ivory. **MAMMOTH IVORY** or **FOSSIL IVORY** is found in large quantities in the region at the mouth of the Lena, partly in the ice or among the glacial stones and partly in caves. The large strongly bowed tusks are from males, the smaller tusks from females. They have a circular cross-section, taper toward the apex, are somewhat spirally twisted, and curve nearly into a circle. The weight as a rule is 60–75 kg., but in exceptional cases reaches 250 kg. Not infrequently they have, within, tangential clefts, the so-called "round cracks" which are not visible on the surface and ruin the material for technical purposes.

AFRICAN ELEPHANT IVORY, the most important ivory of commerce, is obtained from both the west and east coast of Africa. The largest tusks are over 2 m. long and up to 60 (according to CUVIER up to 175) kg. in weight. The tusks from the females weigh only 5–8 kg. The West African product is hard, transparent, and is known as living or glass ivory, while the East African is soft, opaque, white, and is therefore designated milk ivory.[2]

---

[1] [illegible]: Beitrag zur Kenntniss des Zahnbeines von Elephanten, Nilpferd, Walross und Narwal. Jahresb. Wien. Hand. Akad. 1881. 2 [illegible]. v. Höhnel: Beitrag zur Kenntniss der technisch verwendeten Elfenbeinarten. Zeitschr. Nahr. Unters. Hyg. Warenk. 1892. 6 [illegible]. This paper by v. Höhnel is the most exhaustive that has yet appeared on the microscopy of ivory.

[2] For further particulars see the following: Strunck: Ueber die Eigenschaften des Elfenbeins. Dingler's Polyt. Jour. 88 [illegible]. Westendarp: Mittheil. Geog. Gesell. Hamburg. [illegible]

INDIAN IVORY is obtained almost entirely from wild elephants but at present only in small quantities. It is finer and tougher than African ivory, and the tusks seldom reach 40 kg. in weight.[1]

The internal structure of all three varieties of ivory is the same. It consists of dentine, with a thin outer layer of cement but no enamel. At the base is a conical cavity in which (in the living tooth) is contained the pulp. Not infrequently the pulp becomes ossified at the end and forms a special tissue element, **Osteodentine**, which forms balls or conglomerates and injures greatly the quality of the material. With regard to the wearing away of the tusks by use and the replacement with a new growth, v. HÖHNEL states as follows: "The young tusk loses by use so much from its apex that the pulp is finally laid bare; the latter, however, has in the mean time formed new dentine, thus filling the cavity previously occupied by pulp with osteodentine. This osteodentine forms a more or less axially arranged streak extending from the living pulp to the apex. New dentine is formed on the inner side of the old, so that the tusk finally consists of numerous dentine cones, one within the other, the apices of which are closed by the osteodentine core."

In a polished, exactly median, longitudinal section we see the remains of the pulp cavity in the form of a dark streak extending to the apex of the tooth, also the thin cement, the dentine, and, if appreciably developed, the osteodentine.

Four kinds of lines may be distinguished in the dentine, as follows:

(1) DENTINE CANALS.—With a strong lens may be seen very delicate, regularly wavy lines, always at right angles to the outer surface; these are the dentine canals. With stronger magnification the lines show double contour and are but one-third to one-half the breadth of the portions of ground substance between them. Usually they are 1–1.5μ, but the broadest are 3μ. As noted by v. HÖHNEL, the number found in radial section is constant, being 190–225 per millimeter. These canals send off branches which at the base form sharp angles with the main

---

[1] Ivory is used for various articles, the four most important being billiard balls, knife handles (in Sheffield 200,000 kg. are annually used for this purpose), combs, and piano keys. Other articles made of this material are paper knives, umbrella handles, fans, carvings, etc. The centers for working ivory are Sheffield, Vienna, Dieppe, Nüremberg and Fürth, Geislingen near Ulm, Leipzig, and the Bavarian highlands. Ivory raspings serve in place of blotting sand, while the finely ground product is used as a stuffing material and for the manufacture of composition balls.

Ivory is quite easily worked and takes a beautiful and lasting polish. It turns yellow with age, but may be restored to its original whiteness by bleaching.

canal, but further on run parallel to it. Cross-sections of the canals themselves, seen in tangential sections of the tusk, are flattened or elliptical, not circular, showing that the canals are flattened. In cross-sections of the tusk only the narrow sides of the canals are evident; such sections do not show the wavy course of the canals, but they do show more numerous branches. As above stated, these dentine canals are always radially—never axially—arranged.

(2) CONTOUR LINES.—A second system of lines—or more correctly bands—may be seen under the lens. These in radial section (Fig. 252)

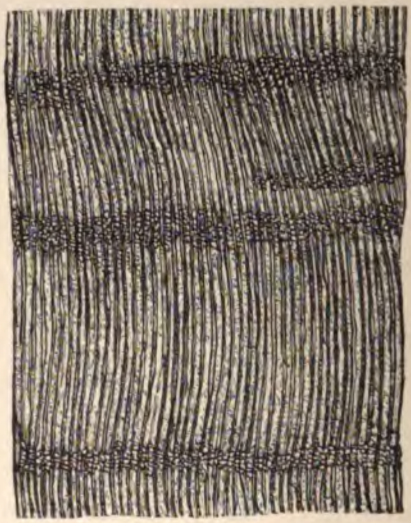


FIG. 252. Elephant Ivory. Radial Section. ×260. (FRITZ OBERMAYER.)

appear as darker or lighter streaks or bands perpendicular to the wavy dentine canals; in cross-section they form delicate lines parallel to the outer surface of the tusk. Their contour in radial section is for the most part obliterated, their breadth unequal (usually 8–15μ, very broad ones up to 30μ or more). These contour lines are due to aggregations of the small, rounded—never slit-shaped—interglobular spaces which often lie close to the dentine canals, conforming to their undulations. Parts of the ground mass which show no contour lines are entirely structureless.

(3) AUGMENTATION ZONES.—This and the following system of lines are visible to the naked eye. As has been described, the method of growth consists in the formation of dentine cones one within the other. These in radial section are distinctly visible and in cross-section form

alternate darker and lighter concentric circles which may be appropriately designated zones of growth or augmentation zones. The contour lines run parallel to these.

(4) SCHREGER LINES.—The fourth system of lines is especially haracteristic of elephant ivory. These so-called Schreger lines are escribed by v. HÖHNEL as follows: "This term is applied to the streaks ue to undulating dentine canals. Since the wavy lines of the successive nals are parallel, there are formed reflection phenomena in the form tangentially or diagonally arranged, often crossing, lines, or else narrow, rker and lighter bands which change in position according to the angle illumination. The markings formed in this manner are known as Guilloching of ivory. True guilloching with crossing bands and mbic meshes occurs only in ivory from species of *Elephas*. In radial tion they run nearly parallel to the surface and at right angles to the tine canals. They are always better developed in the outer part of dentine than in the inner, where they increase in breadth and in distinctss until they finally disappear."

v. HÖHNEL explains the phenomena as follows: "If the light falls rpendicularly on the dentine canals of a radial section, each wave ppears half light and half dark. Since the successive canals run parallel one another there are formed alternate light and dark streaks, each e breadth of half the wave length and, naturally, perpendicular to the anals. If with the same illumination the mount is turned about 180° on he microscope stage, what were crests in the former position are now alleys, and therefore the former dark streaks are now light. If the ount is turned 90° further so that the light falls parallel to the canals, wo places in each canal now appear lighter or darker than the rest and he number of Schreger lines is doubled."

With regard to the formation in cross-section of rhombic meshes y the Schreger lines, v. HÖHNEL states: "If the waves of adjoining anals were all of equal size and equally distant from the periphery, the chreger lines (as in hippopotamus ivory) would all be parallel and ngential. But this is not the case. Cross-sections prepared by grinding show that the crests of the waves correspond with the Schreger lines. hese waves, however, are periodically larger and smaller, thus forming he rhombic meshes. At the corners of the meshes the waves are largest, t the sides smallest."

Tangential sections under the microscope usually appear cloudy, lso many times without markings. The cloudy patches are arranged in longitudinal streaks since the cross-sections of the dentine canals form horizontal wavy lines.

The **Crown Cement** contains bone corpuscles and Havers' canals, the latter being numerous in the tusks of the mammoth, but few in those of African and Indian elephants.

In the foregoing pages we have considered somewhat in detail the structure of elephant ivory and have studied the elements found in teeth. We will now learn with the aid of cuts the chief microscopic characters of other kinds of ivory.[1]

HIPPOPOTAMUS IVORY.

This material is obtained chiefly from the lower tusks (canines) of *Hippopotamus amphibius*, although the upper tusks, the upper and lower incisors, and other teeth are also utilized to some extent. The lower tusks are curved in a half circle, wrinkled on the outer surface, triangular in cross-section, up to 60 cm. long, and, excepting the surfaces of contact, covered with white cement. On drying, the teeth split into two equal longitudinal halves. The dentine is pure white, hard, and shows a delicate guilloching. As seen in radial section (Fig. 253), the dentine canals

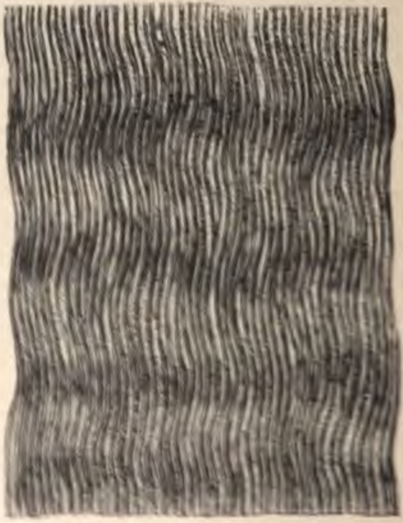


FIG. 253. Hippopotamus Ivory. Radial Section of a Lower Tusk. X160. (FRITZ OBERMAYER.)

---

[1] More exhaustive descriptions will be found in v. Höhnel's paper, *loc. cit.*

are 2–5μ broad, with somewhat irregular, short, curved waves of about 90°. The ground mass shows a globular structure, the interglobular spaces being rounded, arranged in numerous dense layers, but not in distinct contour lines. Tangential sections show kingly the large, irregularly formed cross-sections of the dentine canals which are arranged in rows.

WALRUS IVORY.

The tusks of the walrus (*Trichechus rosmarus*) are 0.5–1 m. long, gently curved, strongly flattened, with a large pulp cavity extending to the very end. The pulp itself is ossified as far as the base of the tooth and forms the hard **Maser** (osteodentine core), which, however, is of no technical use. The teeth while still young have an enamel cap which is soon worn away by use. The radial section (Fig. 254) shows characters which furnish means of distinguishing with some certainty this kind of ivory from others. v. Höhnel states as follows: "The dentine canals are quite straight, 1–1.5μ broad, and show numerous fine anastomosing branches which are bowed outward. The interglobular spaces are large and conspicuous, forming for the most part what appear to be bent clefts. Often they remind one of swallows soaring in the distance. Here and there they form distinct contour lines. The globular structure of the ground mass is very distinct, the globuli being 10–20μ in diameter.

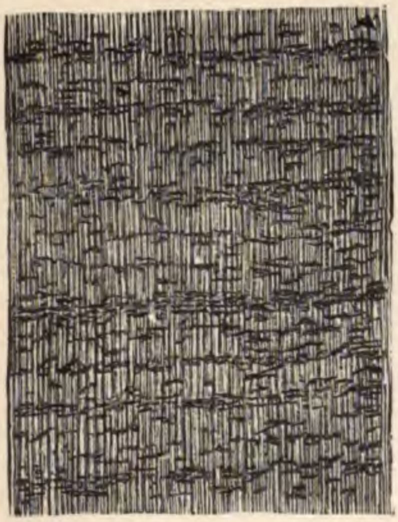


Fig. 254. Walrus Ivory. Radial Section of Tusk. ×260. (Fritz Obermayer.)

The cross-section is of similar appearance except that the dentine canals, seen on their narrow sides, are but 0.3–0.5μ broad." In tangential section the network of interglobular spaces is evident and the lumens of the dentine canals are seen to be incased in a thick, oval (in cross-section) sheath.

NARWHAL IVORY.

The teeth of this animal are straight, 2–3 m. long, twisted spirally to the right, provided with numerous cracks and clefts, and covered with a cement.

Radial sections show wavy and branched dentine canals, also very large interglobular spaces forming a network. In cross-section the dentine canals are straight, the interglobular spaces large and grouped so as to form numerous contour lines which are partly isolated, oftener, however, close side by side (Fig. 255). The cement is laminated and shows beautiful bone corpuscles which are not compressed.

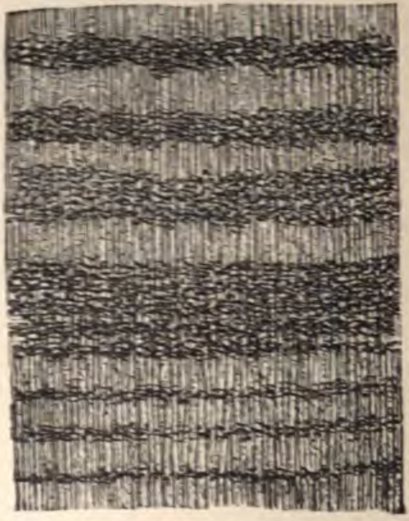


FIG. 255. Narwhal Ivory. Cross-section of Tooth. × 260. (FRITZ OBERMAYER.)

SPERM-WHALE IVORY.

The teeth have cement, dentine, and osteodentine. The crown cement is almost white, the dentine brownish yellow, the osteodentine amber-yellow and hyaline. Four systems of lines are evident in the dentine. In radial section the dentine canals are straight, except in the cloudy places, soaking in cold and hot water, immersing in melted tallow, and pressing with hot iron plates.

Ox Horns.—The raw material of chief commercial importance is horn from oxen and cows, the best grade of which is obtained mostly from South America, although the horns of Hungarian and Galician cattle are also much sought after. Horns of this class are round in cross-section.

Buffalo Horns are finer and harder, therefore better suited for polishing, although, owing to their dark color, they can not be used for transparent objects. The commercial product is obtained from India, Asia Minor, Roumania, and Hungary. They are triangular in cross-section.

Sheep Horns are transparent and therefore well adapted for lanterns and umbrella handles, as are also **Goat Horns**.

Horn Refuse such as shavings and sawdust is made into animal charcoal, used in the preparation of potassium ferrocyanide, in the conversion of iron into steel (case-hardening), and also, after pressing with the aid of heat into a hard mass, for the manufacture of buttons, boxes, etc. A nitrogenous fertilizer is obtained by roasting or steaming horn refuse. On steaming, it forms a soft, elastic mass, which is easily ground; in which form it constitutes the horn meal of commerce.

MICROSCOPIC STRUCTURE.[1]

A cross-section is cut through the point of an ox horn and mounted in water. In this, with moderate magnification (about 70 diameters), we see the central canal (Fig. 256, *cm*) surrounded by light-colored concentric circles which toward the periphery pass into wavy lines. Here and there we find brown spots, often in groups, which might be taken for normal pigment bodies, but in reality are secondary decomposition products of the horn cells (*z*). We also notice small **Marrow Canals** (*m*), although these are distinctly seen only after the action of acetic acid on the section.

The wavy layers are particularly distinct in a section cut through the lower part of the solid portion of the horn (Fig. 257). Such a section also shows clefts (the dark lines in Fig. 257), which, however, do not mark the contours of zones of growth, but are secondary formations.

---

[1] O. Nebeski: Beiträge zur histologischen Charakterisirung der Hornmaterialien. Jahresb. Wien. Akad. 1883, **11**, 208–220.

For the purpose of studying the tissue elements which make up the system of layers, and therefore the bulk of the horn, we treat a thin cross-section with acetic acid and examine it with a magnification of 300 diameters.

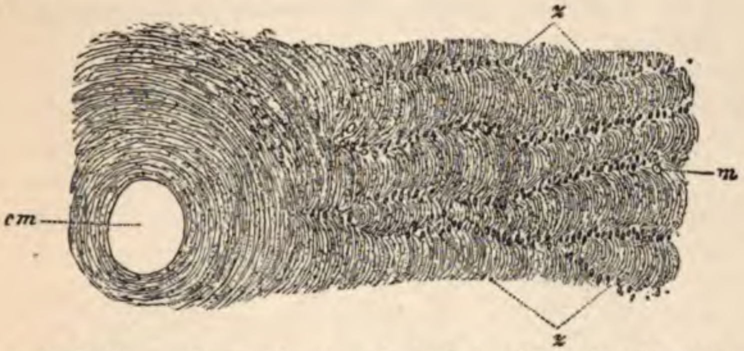


FIG. 256. Ox Horn. Cross-section through the Point, in Acetic Acid. ×70 circa. (O. NEBESKI.)
z brown masses; m marrow canal; cm central canal.

We find that the horn consists in large part of narrow, flattened, in cross-section triangular or elliptical, in surface view broad, cells with a strikingly large, lustrous nucleus (Fig. 258). After treatment with potash, these **Horn Cells**, although swollen, are more sharply defined.

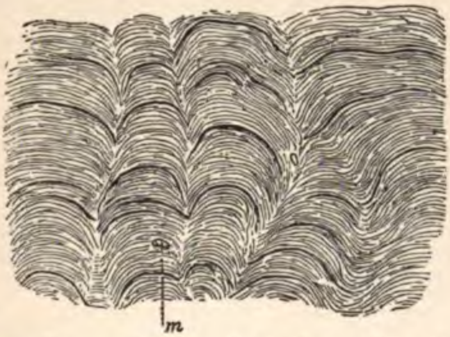


FIG. 257. Ox Horn. Cross-section through the Lower Part of the Solid Horn, in Water. ×70 circa. (O. NEBESKI.)

The arrangement of the cells conforms in general to the surface of the horn; only about the marrow cells are they in small concentric zones.

The wavy streaks or layers (Fig. 257) are due to a peculiar arrangement of the horn cells (Fig. 258). Beginning with the inner surface of the hollow part of the horn, we find lines of narrow but high cells (*x*) perpendicular to the outer surface, between which lines the cells are so arranged as to form more or less parallel bows. These rows of bows are extraordinarily distinct in ox and cow horn, are sometimes absent in buffalo horn, and are almost always absent or very indistinct in sheep horn.

Both the central canal (Fig. 256) and the much smaller marrow canals contain groups of cells which are clearly evident only in sections of living horn. These are known as papillæ and correspond to the papillæ of the second important layer of animal skin (cutis). The marrow canals for the most part extend outward diagonally so that in transverse and tangential sections of the horn they are cut transversely or obliquely, while in radial sections they are cut longitudinally. More of the canals are seen in sections of the outer part owing to their tendency in this part to run parallel to the longitudinal axis.

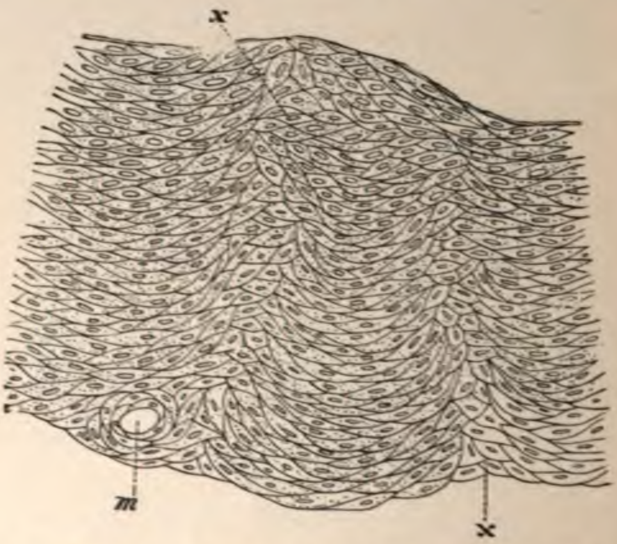


FIG. 258. Buffalo Horn. Cross-section of Inner Layers of Hollow Part, in Acetic Acid. ×300 circa. (O. NEBESKI.)

m marrow canal; *x* radial rows of horn cells between which the flat horn cells extend in curves.

The distinction of the different kinds of horn is very difficult and deserves further study. NEBESKI[1] gives the following scheme based on the number and size of the marrow canals and the distinctness of the rows of bows:

---

[1] *Loc. cit.* 216.

	Rows of Bows.	Marrow Canals.
Ox horn	Very distinct	Very few (diameter 18–46μ)
Buffalo horn	Distinct or absent	Numerous (diameter 20–60μ)
Sheep horn	Indistinct or absent	Numerous and large (diameter 30–160μ)

Hoofs of bovine cattle also consist of flattened cells which swell greatly and contain very numerous marrow canals.

TORTOISE SHELL.

Tortoise shell[1] consists of the horny plates forming the protective covering of several species of tortoise or turtle, especially the hawk's bill or tortoise shell turtle (*Chelone imbricata*) of the Caribbean Sea. This latter species has an ovate, somewhat convex, dorsal shell up to 1 meter long, with prominent horny plates and an almost flat ventral shell with plates much less strongly developed. The distribution of the dorsal plates is as follows: Covering the longitudinal axis are five, for the most part sharply keeled, middle or vertebral plates; on each side of the last are four side plates (in all eight) and about the border of the shell twenty-five marginal plates, which because of their thick claw-like form are known as " claws ", " feet ", or " noses ". These dorsal plates cover one another like the shingles of a roof.

The main ventral plates are in two rows and are divided according to their position into throat, arm, or upper breast, breast, abdominal, lower abdominal, buttock, and groin plates. The large dorsal plates, the marginal plates or claws, and the ventral plates are used extensively at the present time for making useful articles.

Tortoise shell is hard, smooth, very elastic, and takes a high polish. When cold it is somewhat more brittle than horn, but has a much stronger luster and welds so completely that the plates can be joined to form pieces of any size and scraps united and utilized. Dorsal and ventral plates are not only different in thickness but also in color. The former are mottled with flame-like markings on a dull-green to black-brown background. These markings are rose-red, tan-colored, etc., and are lighter and more transparent than the ground color. They take the form of streaks which start at one place in each plate, usually at one of the rear angles, and sometimes spread to such an extent that the original ground color appears to form the markings (BREHM).

Especially valuable is the dark-yellow, spotted East Indian tortoise shell. Next follows (or is of equal value) the Chinese, while the characteristic red-yellow splashed West Indian and the red-brown mottled Egyptian shells are of much lesser value. At present the light or pure yellow material from the marginal and ventral plates is especially sought after. The dorsal plates differ in value according to their position. The two middle side plates on each side lead as to size and thickness and are known as the "chief plates"; next follow in point of value the two anterior side plates and the two posterior, the four keeled central plates, and the five-cornered head plate.

---

[1] T. F. HANAUSEK: Lueger's Lexikon der gesammten Technik, **17**, 229.

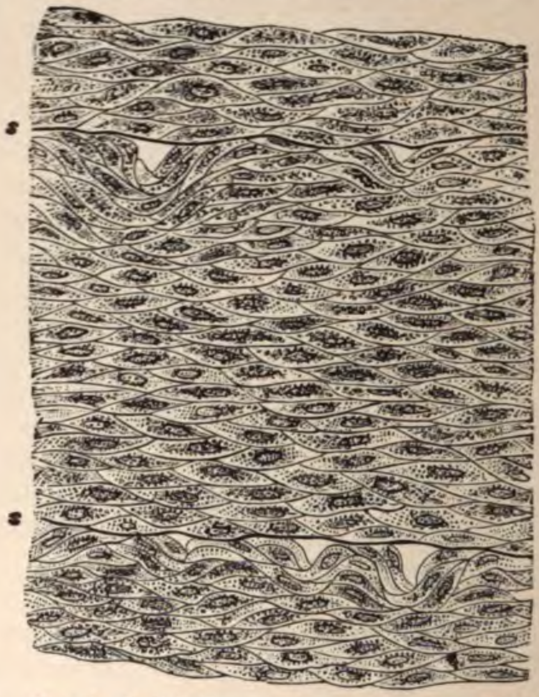


FIG. 259. Tortoise Shell in Cross-section. ×500 circa. (O. NEBESKI.)
The drawing represents the appearance in water, also the boundary lines seen after treatment with potash.

The plates of the green turtle and other species are also utilized; the former, being of a uniform color, is usually colored artificially in imitation of true tortoise shell.

As a preliminary preparation tortoise shell is first cleaned by sand-papering or shaving with glass, then pressed between the warmed plates of a screw press and allowed to cool in the press. The material is used for numerous articles, among which are boxes, combs, hair
eye-glass frames, veneer, buttons, and various trinkets.

MICROSCOPIC STRUCTURE.[1]

With the aid of the microscope the numerous imitations of tortoise shell are easily distinguished from the genuine. Water mounts serve for the distinction from horn, since tortoise shell shows its structure clearly in this medium. The **Horn Cells** of tortoise shell have very sharp contour, are 32–55μ long and about 5–9μ thick. Like those of horn, they are true plate cells with a shining, disc-shaped nucleus and (in the dark parts) with numerous pigment grains. Acetic acid swells the cells but slightly, strong potash somewhat more. Treatment with the latter reagent brings out a distinct laminated structure, since the layers, each 10–20 cells thick, are sharply separated from each other by distinct lines (Fig. 259, *s*).

Marrow Canals are absent. By this negative character, as well as the uniform lamination and the sharply defined cells, the smallest piece of tortoise shell may be easily distinguished from horn.

Horn is made to resemble tortoise shell by coloring with a mixture of lime, potash, graphite, and ferric oxide, or by burning flowers of sulphur previously sprinkled on the surface. Other substitutes are gelatine, delimed ivory, celluloid, etc.

WHALEBONE.

Common whalebone, or baleen, consists of the triangular, less often quadrangular, horny plates found in cross-rows in the roof of the mouth of the Greenland whale (*Balæna mysticetus*).[2] An unimportant kind, of a uniform dark color, is obtained from the fin whale (*Physalus antiquorum*=*Megaptera boops*).

The horn plates in a single animal number 300–600, with a total weight of 750 to 1600 or, so it is said, 2500 kg. They rest against the plowshare bone (vomer). Each plate is black-brown to black, greenish gray at the base, smooth on the broad surfaces, and separates on its largest longitudinal surface into fibers. The length of the plates is 1.5–04 meters, dependent on the age of the animal and their position in the mouth, those in the middle being the longest. Considering the plates

---

O. Nebeski: *loc. cit.* 208–210.

[2] T. F. Hanausek: Lueger's Lexikon der gesammten Technik, 4, 273.

as right-angle triangles, the longest arm is attached to the roof of the mouth, the shorter extends downward at right angles to the jawbone, while the hypothenuse extends downward, breaking up into fibers (**Brehm**).

Whalebone owes its value to its high elasticity, marked toughness and tensile strength, hardness, and remarkable cleavability, which is not equalled by any kind of wood. This high cleavability, under some conditions, is a decided disadvantage, causing the material to split during use.

The plates after being removed from the whale and freed from adhering fat and skin are packed in bundles of 10–12 for shipment. Sometimes the plates are split before packing. In the factory they are freed from the loose fibers—which are utilized as a substitute for horse hair—and sawed into the longest possible lengths. These latter are softened in hot water, fastened in a vise, and cut with special knives, according to the uses for which they are intended, into pieces of various forms as follows: (1) four-sided rods for umbrellas; (2) flat strips for corsets[1] and extra broad strips (up to 3–4 cm.) for use in polishing; (3) thin rods for weaving into the frames of women's hats; and (4) pieces suited for making canes, whips, fine baskets, trinkets, etc. The shavings, like the loose fibers, yield a substitute for horse hair.

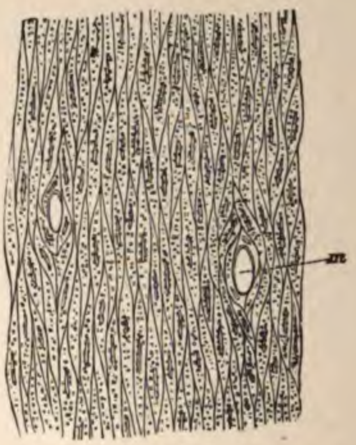


Fig. 260. Whalebone. Cross-section of the Outer Lamella. × 300 circa. (O. **Nebeskl**)

---

[1] Whalebone was used in largest amount at the time when the rococo style was in vogue, enormous quantities being required for the armor-like corsets and the voluminous hoopskirts.

MICROSCOPIC STRUCTURE.[1]

The structure is that of a horn tissue. Again we find the ground tissue of plate-shaped **Horn Cells** each with a nucleus, also numerous

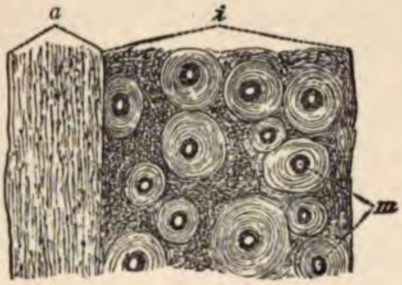


FIG. 261. Whalebone. Cross-section of Baleen in Water. ×70 circa. (O. NEBESKI.) *a* outer lamella; *i* middle layer with *m* marrow canal (horn tube). The outer lamella on the right is not shown.

Marrow Canals. Owing to a peculiar arrangement of the horn cells the structure of the outer layers is quite different from that of the middle zone. In cross-section the two outer rather thin lamellæ (Fig. 261, *a*) are lighter colored and more homogeneous, the middle layer (*i*) is darker and shows under the lens numerous pores. The outer layers (Fig. 260) consist of large thin plate cells 60–90μ long and 2–3μ thick, the contours of which are distinct after treatment with acetic acid or soda. Very small, narrow cells parallel to the longitudinal axis of the horn plate are also visible. The middle layer (Fig. 261, *i*) consists of numerous

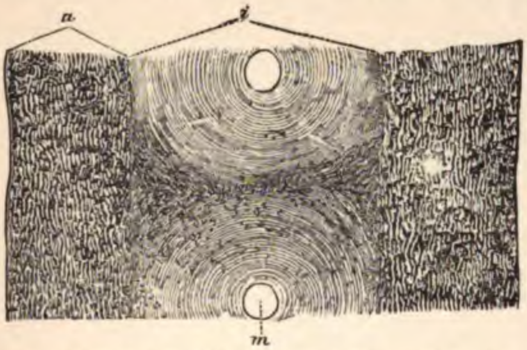


FIG. 262. Fin-whale. Cross-section of Baleen in Water. ×70 circa. (O. NEBESKI.) *a* outer lamella; *i* middle layer with *m* marrow canal (horn tube).

---

[1] O. NEBESKI: *loc. cit.* 217.

longitudinally arranged cylindrical tubes,[1] made up of concentrically arranged plate cells and containing in their cavities papillæ of connective tissue. It is remarkable, as noted by NEBESKI, that only the two or three cell layers immediately surrounding the canals contain pigment in considerable amount (*m*), so that the cross-section of each canal appears to have a dark inner border.

The horn plates of the fin whale consist of three layers (Fig. 262). The outer layer, because of the extraordinary accumulations of pigment deposits (*a*), is easily distinguished from the corresponding layer of whalebone. Even more striking is the difference in the middle layer, which in the fin whale consists of only a single median row of horn tubes (*i*), with no marked accumulation of pigment in the inner rows of cells.

A substitute for whalebone made from rattan is described on p. 256.

Other substitutes are Indian buffalo horn and colored istle fiber from *Bromelias*, which comes into the market under the name of coraline.[2]

---

[1] These horny tubes may be regarded as homologous to hairs.

[2] SEMLER: Trop. Agr. 3, 709.

CHAPTER IX.

MICROCHEMICAL ANALYSIS.

As early as 1866, HARTING, in Part II of his work on the microscope,[1] recommended the application of this instrument for the study of crystalline precipitates such as calcium carbonate, calcium oxalate, and barium sulphate. A year later WIESNER published his introduction to technical microscopy,[2] which also treats of the microscopic investigation of unorganized substances, including determinations of crystallographic characters, index of refraction, etc. Of the greatest importance is microchemical analysis, which, like chemical analysis, determines the composition of chemical substances by means of reactions, color tests, the formation of precipitates, the evolution of gases, and the observation of crystalline forms.

In previous chapters we have made use of microchemical analysis for various purposes. For example, to determine whether crystals in a vegetable tissue are composed of a lime salt, we have treated them with dilute sulphuric acid, which forms with lime gypsum needles. Again we have demonstrated the presence of carbonates in bones by the evolution of carbonic acid on treatment with hydrochloric acid. It is, however, only since petrographists began to apply microchemical methods to rock analysis that these methods have been productive of important results and have reached a high degree of usefulness. Although the technical microscopist is concerned chiefly with organized raw materials, still occasionally he finds it important to determine the chief constituents of crystalline precipitates observed in microscopic mounts. Not infrequently such crystalline formations make their appearance on the addition of reagents.

It is not within the scope of this work to present a comprehensive and systematic treatment of this branch of microscopic investigation who desire to make a special study of this subject are referr works of HAUSHOFER,[1] KLÉMENT and RENARD,[2] LEHMANN,[3] RENS,[4] and CHAMOT.[5] BEHRENS has not only developed methods for microscopic analysis, but has also published a work ing admirable instructions for the preparation of permanent m well as for carrying out the processes of sublimation and crystal

---

[1] Theorie und allgemeine Beschreibung des Mikroskopes. Braunschweig, 2. Aufl. 1866.

[2] Einleitung in die technische Mikroskopie. Wien, 1867.

There are several methods which serve to determine the id composition cf materials or to detect impurities.

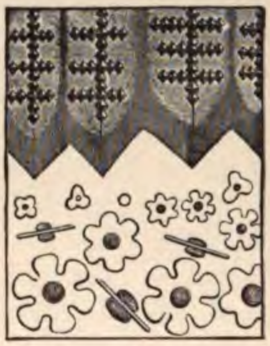


FIG. 263.

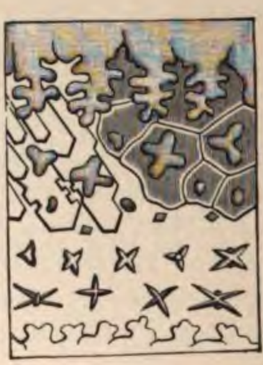


FIG. 264.

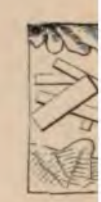


FIG.

FIG. 263. Fusion Test with Lead Nitrate and Saltpetre. (LEHMANN.)
FIG. 264. Fusion Test with Silver Iodide and Potassium Iodide. (LEHM
FIG. 265. Solution Test with Silver Nitrate and Saltpetre. (LEHMANN.)

Comparative Crystal Analysis.[3]

This general method rests on the principle that two substan be investigated together in the same fused mass or solution, the t being such as to cause a definite separation. The crystals or pa each of the two substances thus separated may be in distinct g aggregates or else intermixed with those of the other substance as well as the other methods of examination, depends almost invariably on the formation of crystals; amorphous substances, whether formed by precipitation or fusion, are usually of little service in diagnosis.

---

[1] Mikroskopische Reactionen, eine Anleitung zur Erkennung verschiedener und Verbindungen unter dem Mikroskop. Braunschweig, 1885.

[2] Reactions microchimiques à cristaux et leur application en analyse qualita xelles, 1886.

[3] Die Krystallanalyse oder die chemische Analyse durch Beobachtung der bildung mit Hülfe des Mikroskops. Leipzig, 1891.

[4] Anleitung zur mikrochemischen Analyse. Hamburg, 1. Aufl. 1875, 2. Aufl.

[5] Chemical Microscopy. New York, 1915.

[6] Mikrochemische Technik. Hamburg, 1900.

FUSION TESTS are conveniently carried out as follows: A granule of one of the substances is placed on the slide, covered with a cover glass, and cautiously melted. For extended investigation or frequently applied tests it is recommended to use an arrangement[1] whereby the warming is performed by a small gas flame inserted through an opening in the stage of the microscope and quickly removed. A grain of the second substance is next placed at the edge of the cover glass and melted so that the fused mass penetrates beneath the cover glass and comes in contact with the first substance.

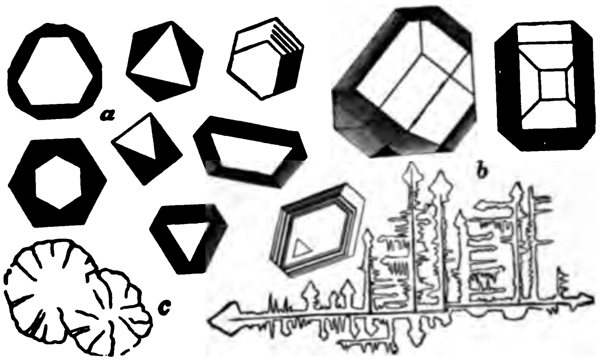


FIG. 266. Detection of Aluminium as Cæsium Alum. (HAUSHOFER.)
At the right dedrites formed in the presence of more than one per cent of aluminium.

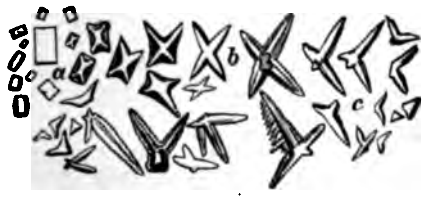


FIG. 267. Barium Sulphate, Crystallized from Concentrated Sulphuric Acid. (HAUSHOFER.)

We will consider two striking examples of this method of separation.

EXAMPLE 1. If grains of lead nitrate and saltpetre are treated as above described, it will be observed that, after the two fused masses come in contact and again are on the point of solidifying, the lead nitrate forms a beautiful crystalline skeleton in a cloudy mass, while the saltpetre separates as entirely free hexagonal stars (Fig. 263). The zone of contact of the original fusions remains longer in the fluid condition, then changes into a cloudy or glassy amorphous mass into which the crystals as formed do not penetrate.

---

[1] See illustrations in LEHMANN: *loc. cit.* p. 5, Fig. 1, and p. 6, Fig. 2.

EXAMPLE 2. Fig. 264 shows the fusion products of silver iodide and potassium iodide. Here again three zones are formed. At the top we note coarse yellow crystals of silver iodide, at the bottom crystals of potassium iodide, and in the middle zone a dark-brown mass, in which (at the left) are tabular crystals of a new compound with hexagonal outlines.

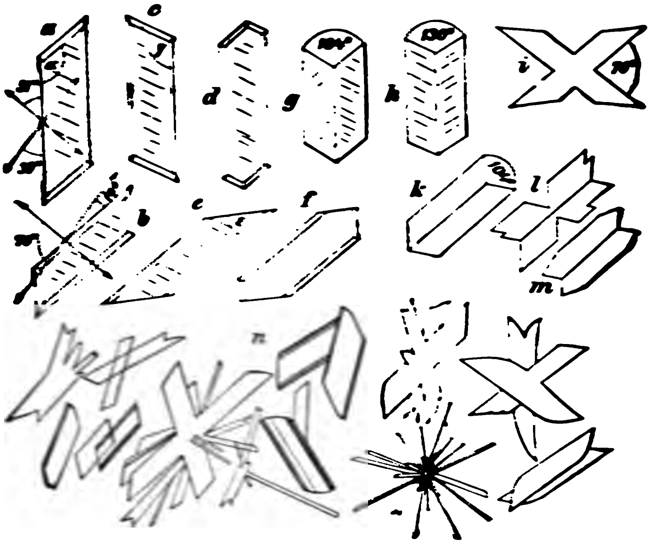


FIG. 265. GYPSUM. (HAUSHOFER.)

In the two upper rows are diagrammatic figures to elucidate the crystals obtained by crystallization shown below. a and b = (010) (110) (111); c = (010) (110) (111); d = (010) (110) (111) (111); e without (110); f with weakly developed (110); g, h, i, l, twin forms of (100) and (101).

SOLUTION TESTS.[1]—Tests by this method depend on the comparison of crystals formed from solutions. In preparing the mounts a small amount of the material is placed on a slide, the solvent is added, and the slide is warmed slightly. After all the material has dissolved, a little more is added or else the solution is evaporated until a portion remains undissolved; thereupon a portion of the second material is brought under the cover glass and the slide is again warmed.

---

[1] LEHMANN: *loc. cit.* 18.

A mount thus prepared with silver nitrate and saltpetre furnishes an example of this test (Fig. 265). On the saltpetre side we find a skeleton of rhombohedrons, on the silver-nitrate side indistinct crystals, in the middle zone rectangular tables of a double salt.

Individual Crystal Analysis.

Of much more importance than the comparative method is that depending on the formation of a crystalline compound of an element by means of a chemical reagent. It requires some experience to determine the proper amount of the reagent for successfully carrying out the test. In many cases indistinct crystal aggregates, not distinct crystals, are formed, and it is necessary to repeat the operation until the proper conditions are learned. The authors already cited give full instructions as to details.

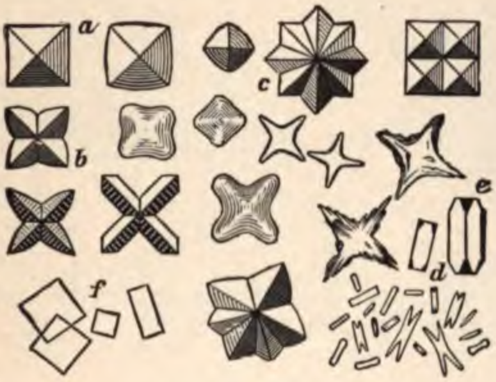


FIG. 269. Calcium Oxalate, Precipitated Cold. (HAUSHOFER.)

Following are examples of microchemical reactions for a number of well-known substances.

Aluminium.—For the detection of alumina BEHRENS employs cæsium chloride, which precipitates from sulphuric-acid solution of the sample cæsium alum. He describes the test as follows: "The drop to be tested is evaporated with a small drop of sulphuric acid, the residue dissolved in a little water and a small grain of cæsium chloride added at the edge. The proper concentration is essential for the success of the operation. If more than 1 per cent of aluminium is present, rectangular dendrites form about the cæsium chloride, in which case a drop of water should be added; with less than 0.2 per cent of aluminium it is difficult to secure good crystals. The crystals of cæsium alum are beautiful, colorless octahedrons (Fig. 266). Cæsium sulphate may also be employed.

Barium.—The barium salt (sulphate or heavy spar) is dissolved in concentrated sulphuric acid, a hot drop placed on the slide and allowed to cool. Thereupon very small, rectangular scales (Fig. 267, *a*) separate or, on saturating the sulphuric acid with the salt, there are formed x-shaped crystal skeletons (*b*) or distorted triangular forms (*c*).

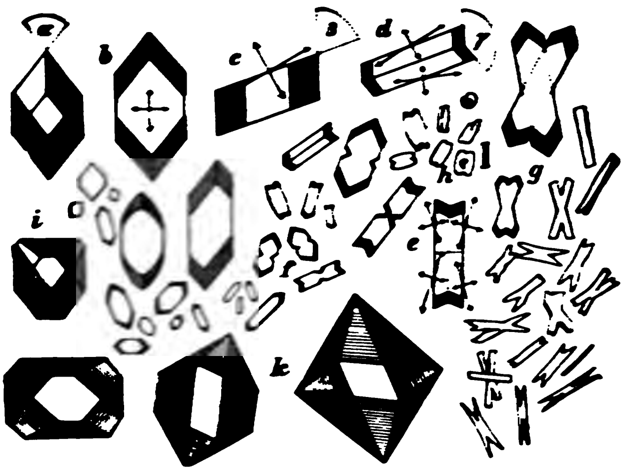


FIG. 270. Monoclinic Calcium Oxalate, Precipitated Hot. (HAUSHOFER.) *b* = 001 (110) (010); *c* shows characteristics of rhombohedrons (001) (110); *d* twins, twinning plane = 001; *d*–*h* twins; *k* crystals resembling octahedrons formed by the nearly equal development of surfaces (110) (001) and (101); *i* transition form to *k*.

Calcium.—This element is usually detected by the formation of gypsum, that is, crystallized calcium sulphate with two molecules of water. The crystalline forms of gypsum are easily recognized under the microscope, the best known being (010) (110) (111) and swallow-tail twins; in addition we find needles and stellate aggregates formed during rapid separation (Fig. 268).

Calcium oxalate, which occurs so frequently in vegetable tissues, forms tetragonal crystals with three molecules of water ($CaC_2O_4+3H_2O$) and monoclinic crystals with one molecule ($CaC_2O_4+H_2O$). Tetragonal crystals are obtained if neutral or ammoniacal calcium solutions are precipitated at ordinary temperatures with oxalic acid. The crystals (Fig. 269) are flat quadrate pyramids, often only skeletons, also stellate orms. From hot solutions are obtained monoclinic crystals = (001) (110) (010) (Fig. 270, *b*) and other combinations, also twin forms

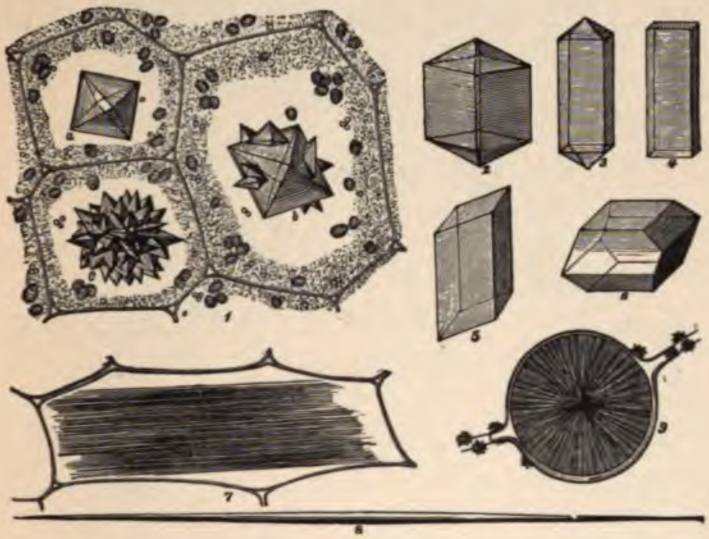


FIG. 271. Calcium Oxalate Crystals of Vegetable Tissues. (KNY.)
1 single crystal from the petiole of begonia; *2–4* tetragonal forms; *5–6* monoclinic forms; *7–8* needle-shaped crystals or raphides from the cells of duckweed (*Lemna*); *9* sphæro crystals from the mycelium of a fungus (*Phallus*).

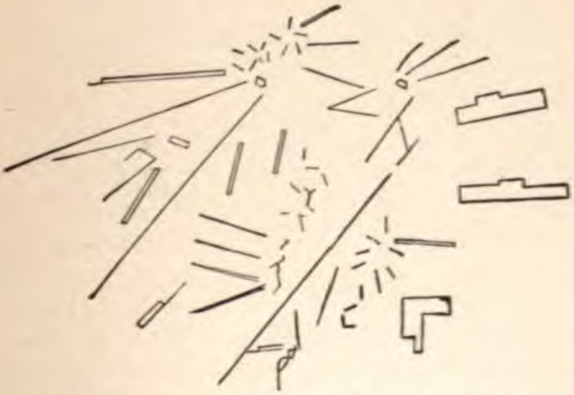


FIG. 272. Chlor-auric Acid in Short Zigzag Rods, Rod-shaped Prisms, and Rectangular Plates. ×400. (T. F. HANAUSEK.)

(*d*, *e*, *f*, *g*, *h*). The commonest crystalline forms in which calcium oxalate separates in vegetable tissues are shown in Fig. 271; we have frequently observed these crystal forms in various products, such as violet root, quillai bark, cottonseed, etc.

In vegetable tissues calcium oxalate occurs both as tetragonal (Fig. 271, *2–4*) and monoclinic crystals (*5–6*). The forms include simple crystals, crystal groups (crystal clusters, crystal rosettes, etc.), needle-shaped crystals, or raphides (*7*), crystal sand,[1] and sphæro crystals (*9*).

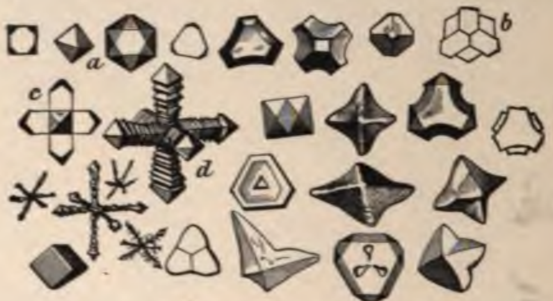


FIG. 273. Potassium Platinichlorid. (HAUSHOFER.)
a octahedron; *b* and *c* groups with three and four limbs; *d* octahedral skeletons.

Gold.—A solution of gold trichloride, somewhat stronger than 3 per cent, forms with concentrated hydrochloric acid characteristic crystal forms. If a drop of the solution is added to a drop of acid there appear on evaporation yellow rod-shaped prisms which are partly short and zigzag and partly strikingly long, but are never fine, pointed needles; also numerous tabular crystals with rectangular projections (Fig. 272). This newly formed compound is chlor-auric acid ($AuCl_4H \cdot 4H_2O$).[2]

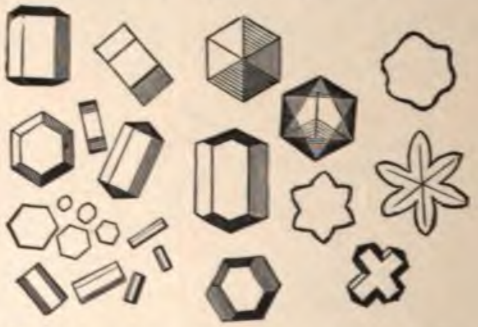


FIG. 274. Sodium Fluosilicate. (HAUSHOFER.)

---

[1] See poppy seed, p. 393.

[2] T. F. HANAUSEK: Zur histochemischen Kaffeinreaction. Ztschr. allg. Öst. Apoth. Ver. 1891, 29, 606–608.

Quite as characteristic as the last is the reaction of sodium chloride with gold chloride, whereby pale-yellow, flat prisms of the rhombic system are formed by the side of crystals of common salt.

Much more delicate still is the test employing a mixture of stannous-chloride solution with a little chlorine water. This test gives the well-known purple coloration due to the formation of purple of Cassius and serves to detect very small amounts of gold.

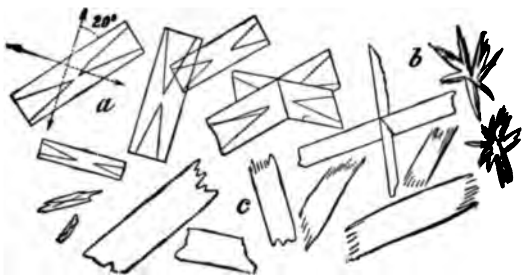


FIG. 275. Silver Formate. (HAUSHOFER.)

Potassium.—Neutral potassium sulphate (K_2SO_4) in the form of rhombic crystals often occurs as a by-product of reactions. Very small amounts of potassium may be detected by chlor-platinic acid (" platinum chloride "), which forms with that base tesseral crystals of potassium platinichloride (Fig. 273). The crystal forms are octahedrons and hexahedrons, also octahedral skeletons (*d*) and crystal groups of 3–4 members.

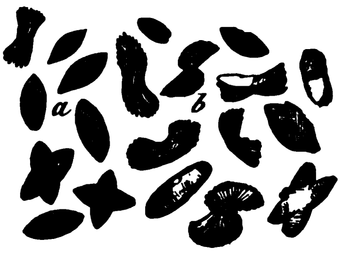


FIG. 276.—Calcium Citrate. (HAUSHOFER.)
a seen from above, whetstone-shaped; *b* seen from the side, sheaf-shaped.

Sodium.—When hydrofluosilicic acid acts on sodium salts or hydrofluoric acid on sodium silicate, there is formed sodium fluosilicate,[1] which separates as crystals belonging to the hexagonal system. These consist of six-sided proto-prisms with proto- and deutero-pyramids, tabular crystals, and skeletons (Fig. 274).

---

[1] BEHRENS: Ableitung, etc., 32. HAUSHOFER: *loc. cit.* 98.

Formic Acid.—This is identified as silver formate (HCO_2Ag). If a formic-acid salt is mixed with silver nitrate, there are formed rectangular tables which on longer action grow into fine fibers or fringes (Fig. 275).

Citric Acid is identified only as calcium citrate. A solution of the acid neutralized with sodium hydrate is boiled with calcium chloride. The crystals which form when seen from above are whetstone-shaped, but when viewed from the side resemble sheaves of wheat (Fig. 276).

GENERAL INDEX.

ele, 239
eltree, 239
ies, 176, 212
  alba, 212
  balsamea, 206, 212
  Canadensis, 287
  firma, 212
  grandis, 212
  pectinata, 212
cia, 327
  decurrens, 281
  homalophylla, 240
cia, false, 208
cessory fruit, 325
companying cells, 298
r, 233
  campestre, 207, 233
  macrophyllum, 233
  platanoides, 207, 233
  Pseudoplatanus, 207, 233
  rubrum, 233
  saccharinum, 233, 234
etic acid, 21
hene, 327
id, acetic, 21
  ceric, 279
  chromic, 21
  hydrochloric, 21
  nitric, 21
  phellonic, 279
  picric, 21
  pyrethrotoxic, 313
  sulphuric, 21
ds, 21
rn, 327
  starch, 33
ansonia paper, 122
nanthera pavonina, 242
mone mirabilis, 253
chynomene aspera, 253
culus, 237
  flava, 238
  glabra, 238
  Hippocastanum, 204, 237
African granadilla wood, 242
  red wood, 252
  rosewood, 240
  sandalwood, 252
Agal wood, 242
Agallochium, 242
Agave, 253
  Americana, 96
  elongata, 97
  Mexicana, 96
  rigida, 97
  Sisalana, 97
  vivipara, 96
Aggregate fruit, 325
Agrostemma Githago, 347, 349
Ailanthus, 208, 219
  silk, 148
Ailanthus glandulosa, 219, 301
Albumen, 331
Alburnum, 207
Alcohol, 23
  hydrochloric acid test for flour, 349
Alcoholic naphthylene blue test for flour, 348
Alder, 207, 208
  black, 229, 231
  buckthorn, 229
  white, 231
Alectorolophus hirsutus, 349
Aleurone layer of cereals, 339
Algaroba wood, 242
Alkali cellulose, 68
Alkalies, 21
Alkanna root, 269
  tincture, 23
Alkanna tinctoria, 269
Alkannin, 269
Almond, 228
Alnus, 231
  glutinosa, 231
  incana, 231
Aloe fiber, 100
"Aloe wood," 253
Alpaca, 139, 141

Alsation process for manufacture of wheat starch, 39
Aluminium, microchemical tests for, 443
American beech, 232
  bird's-eye maple, 234
  green ebony, 242
  linden, 234
  plane tree, 230
  sumach, 300
Ammonia water, 21
Amygdalus communis, 228
Amylodextrin, 35
  starch, 35
Amyloid, 57
Amyris, 240
Anacardiaceæ, 246
Analysis, comparative crystal, 440
  microchemical, 439
Analytical key, Burgerstein's, for spruce and larch woods, 192
  for identification of economic woods, 211
Anatropous ovule, 329
Andira Aubletii, 242
  inermis, 242
Andrœcium, 313
Angora wool, 130
Aniline brown, 23
  sulphate, 22
Animal fibers, 123
  hairs, 123
    cortex of, 123, 125
    cuticular scales of, 123, 125
    epidermis of, 123, 125
    medulla of, 123
    root of, 123
    shaft of, 123
Annual rings, 175, 203
  vessels, 100
Anthocarpous fruit, 325
Antipodal cells, 331
Antlers, deer, 421
Apocarps, 326
  jointed, 326
Apocynaceæ, 273
Apple, 207, 237, 327
Apricot, 228
Aquilaria, 243
Arachis hypogæa, 387
Aralia papyrifera, 120
Araucaria, 213
  Brasiliana, 213
Arbor vitæ, 214
Archangelica officinalis, 360
Arctostaphylos officinalis, 301
  Uva ursi, 301
Arena mahogany, 241
Arenga saccharifera, 47
Aria, 228
  [illegible], 237
Aril, 328
Arillus, 329
Arm of compound microscope, 8
Arrowroot, Bermuda, 43
  Brazilian, 46
  East India, 46
  Guiana, 47
  Malabar, 46
  Queensland, 46
  starch, 33
  Tellicherry, 46
Artificial silk, 151
  Chardonnet, 151
  distinction from mulberry silk, 155
  gelatin, 156
  Hummel, 152
  Langhaus, 152
  Lehner, 152
  Pauly, 156
  treatment with iodine in potassium iodide, 155
  Vivier, 152
Artocarpeæ, 273
Asbestos, 156
  hornblende, 156
  serpentine, 156
Asclepiadaceæ, 273
Ash, 207, 208
  black, 221
  blue, 221
  common, 221
  green, 221
  of flour, 345
  Oregon, 221
  red, 221
  white, 221
Asp, quaking, 238
Aspen, 207, 238
Asperifoliæ, 327
Aspidosperma, 241
Assimilation, 29
Atriplex, 349
Atropous ovule, 329
Attacus Cynthia, 148
Augmentation zones of ivory, 424
Australian boxwood, 241
Autumn wood, 179

Bacca, 327
Baccate syncarp, 327
Baden cherry, 228
Balæna mysticetus, 435
Balausta, 327
Bald cypress, 215
Balm leaves, 300
Balsam cottonwood, 239
  fir, 212
Bamboo, 243
  [illegible] paper, 122
Bambusa arundinacea, 243
Bamihl test for gluten, 346
Banana starch, 47
Bandala, 88
Baphia nitida, 252

- *Baphia pubescens*, 252
- Barberry, 227, 250, 326
- Barium, microchemical tests for, 444
- Bark, oak, 281
  - quillai, 288
  - rays, 285
- Barks, 274
- Barley, 349
  - chaff of, 350
  - four-rowed, 349
  - groats containing 10% of millet bran, mechanico-microscopical analysis of, 358
    - mechanico - microscopical analyses of genuine and false, 357
  - starch, 33
  - two-rowed, 349
- Barsino wood, 242
- Barwood, 252
- Base of compound microscope, 8
- Bass wood, 234
- Bast-fiber bundles, 258
  - fibers, 72, 284
  - hemp, 77
- Bastard mahogany, 241
- *Batatas edulis*, 46
- Batavia four-leaf twill, 158
- Batting, 73
- Baves of silk, 144
- Bay wood, 241
- Beam tree, white, 237
- Bean starch, 49
- Beard hairs, 123, 129
- *Beaumontia grandiflora*, 70
- Bedstraws, 349
- Beech, 208, 209
  - American, 232
  - blue, 232
  - copper, 232
  - harst, 232
  - horst, 232
  - red, 197, 207, 232
- Beechnut cake, 397
- Beefwood, 241
- *Berberis*, 227
  - *vulgaris*, 227, 250
- Bermuda arrowroot, 43
- Berry, 327
  - honey, 223
  - simple, 326
- *Betula*, 235
  - *alba*, 236
  - *lenta*, 236
  - *lutea*, 236
  - *papyrifera*, 236
- Bichromate, potassium, 22
- Bicollateral bundle, 264
- Bindweed, black, 349
- Birch, 207, 208
  - black, 236
  - canoe, 236
  - cherry, 236
- Birch, European white, 236
  - mahogany, 236
  - paper, 236
  - Swedish curled, 236
  - white, 236
  - yellow, 236
- Bird cherry, 229
- Bird's-eye maple, American, 234
  - Hungarian, 234
  - Russian, 234
- Bitter oak, 225, 281
- Black alder, 229, 231
  - ash, 221
  - bindweed, 349
  - birch, 236
  - cork, 275
  - cottonwood, 239
  - cypress, 215
  - elder, 228
  - gum, 234
  - locust, 220
  - mulberry, 220
  - oak, 224, 281
  - palm wood, 243
  - pine, 187, 217
  - poplar, 208, 239, 275
  - spruce, 216
  - walnut, 230
- Blade of leaf, 324
- Blue ash, 221
  - beech, 232
  - woods, 251
- Blueberry, 327
- *Boehmeria nivea*, 90
- Bois de Chypre, 240
  - perdix, 241
  - rose femelle, 243
- *Bombaceæ*, 68, 253
- *Bombax Ceiba*, 68, 368
  - *heptaphyllum*, 68
  - *Malabaricum*, 68, 368
  - *pentandrum*, 368
- Bombay arrowroot, 46
  - hemp, 84
- *Bombyx Cynthia*, 304
  - *Faidherbii*, 148
  - *Mylitta*, 148
  - *Selene*, 148
  - *Yamamaya*, 148
- Bone cells, 420
  - corpuscles, 420
  - true, 418
- *Boraginaceæ*, 269
- *Borassus flabelliformis*, 47
- Bordered pits, 179, 181
  - pod, 327
- Box, 208
- Box-leaved fernelia, 207
- Boxwood, 235
  - Australian, 241
  - Turkish, 241
  - West Indian, 241
- Brasilein, 252

Brasilin, 252
Brassica Napus, 392
  Rapa, 392
Brazil wood, genuine, 252
  Pernambuco, 252
Brazilian arrowroot, 46
  rosewood, 240
  teakwood, 242
Breaking, 73
Breeds of sheep, 124
Brier wood, 235
Bristle hairs, 123
Bristles, 123
British oak, 224, 281
Brittle willow, 238
Broad-leaved maple, 233
  woods, medullary rays of, 196
    of temperate zone, 196
    tracheæ of, 196
    tracheids of, 196
    tropical, 206
    true wood fibers of, 196
    wood parenchyma of, 196
    vessels of, 196
Broom, German, 85
  Spanish, 85
Broussonetia Kampferi, 92
  papyrifera, 92
  tinctoria, 244
Brown hemp, 84
Brya ebenus, 242
Buckeye, Ohio, 238
  sweet, 238
Buckthorn, [illegible], 327
  alder, [illegible]
Buckwheat starch, [illegible]
Bukkum wood, 252
Bull pine, [illegible]
Bullace, [illegible]
Bully tree, [illegible]
Bundles, bast fiber, [illegible]
  fibro-vascular, [illegible]
    bicollateral, [illegible]
    closed, [illegible]
    collateral, [illegible]
    [illegible]
    concentric, [illegible]
    open, [illegible]
    radial, [illegible]
  vascular, [illegible]
    [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

Buttonwood, 230
Buxus, 235
  sempervirens, 235
Cæsalpinia, 240
  Braziliensis, 252
  crista, 252
  echinata, 252
  Sappan, 252
  tinctoria, 252
Cæsalpinieæ, 207
Cæsalpinioideæ, 251
Cailcedra wood, 241
Cake, beechnut, 397
  cocoanut, 403
  cottonseed, 361
  hemp, 395
  kapok, 368
  linseed, 384
  madia, 377
  niger, 375
  palm-nut, 400
  peanut, 387
  poppy, 393
  pumpkin-seed, 369
  rape, 392
  sesame, 380
  sunflower, 377
Cakes, miscellaneous, 406
Calamander wood, 239
Calambac, 242
Calamus, 243
  micranthus, 255
  niger, 255
  Rotang, 255
  Royleanus, 255
  rudentum, 255
  Scipionum, 255
  tenuis, 255
Calcium carbonate, 58
  oxalate, 208
  microchemical tests for, 444
Calcutta hemp, 84
Calf hair, 124
California soapwort, 260
Calotropis gigantea, 70
Calyx, [illegible]
Cambiform cells, 260
Cambium layer, interfascicular, 291
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
  [illegible]
  [illegible]
  [illegible]
[illegible]
[illegible]

- *Canna Indica*, 46
  - starch, 46
- *Cannabis sativa*, 395
- Canoe birch, 236
  - cedar, 214
- Cape mahogany, 241
- Capsule, 326
  - pore, 326
- Carmine, 23
- Carolina nut, 414
- *Carpinus*, 208, 231
  - *Americana*, 232
  - *betulus*, 232
  - *Caroliniana*, 232, 236
- *Carya*, 202, 220
  - *alba*, 222
  - *porcina*, 221
  - *tomentosa*, 222
- Caryopsis, 327
- Cashmere, 131
- Cassava starch, 45
- *Castanea*, 223
  - *sativa*, 226
    - var. *Americana*, 226
- Cat's-paw, yellow, 323
- Caucasian insect powder, 323
- Cavities, excretion, 193
  - lysigenous, 194
  - respiratory, 298
  - schizogenous, 193
  - secretion, 193
- *Ceanothus Chloroxylon*, 241
- Cedar, 208
  - canoe, 214
  - incense, 214
  - Oregon, 213
  - Port Orford, 213
  - red, 189, 214
  - medullary rays of, 189
  - Spanish, 219
    - imitation, 295
  - white, 213, 214
- *Cedrela*, 219
  - *odorata*, 219
- *Ceiba pentandra*, 68, 368
- Cell contents, notes on, 207
  - streaks, 205
- Cells, accompanying, 298
  - bone, 420
  - cambiform, 260
  - companion, 260
  - complementary, 276
  - conducting, 186
  - guard, 298
  - horn, 431, 434, 437
  - libriform, 197
  - of medullary rays, 203
  - sclerenchyma, 277, 284, 290
  - secretion, 265
  - starch, 265
- Celluloid, 57
- Cellulose, 54
  - lamella, 279
- Cellulose silk, action of Fehling solution on, 155
    - color with Millon's reagent, 155
    - treatment with iodine in potassium iodide, 155
  - soda, 116, 118
  - sulphite, 116, 118
- *Celtis*, 203, 208, 222
  - *aspera*, 223
  - *Australis*, 223
- Cembra pine, 218
- Cement, tooth, 421
- Central European oaks, 224
- *Centrolobium robustum*, 240
- Ceratenchyma, 288
- Cereal grains, 327
- Ceric acid, 279
- Cerin, 279
- Ceylon ebony, 239
- Chaff of barley, 350
  - millet, 352
  - rice, 351
- Chaffy wheats, 334
- Chalaza, 329
- *Chamæcyparis*, 213
  - *Lawsoniana*, 213
- Chardonnet silk, 151, 152, 155
- *Charta corticea*, 122
- *Chelone imbricata*, 433
- Chemical wood pulp, 118
- *Chenopodium*, 326
- Cherry, 207, 208, 228
  - Baden, 228
  - birch, 236
  - bird, 229
  - mahaleb, 228
  - mazard, 228
  - morello, 228
  - sour, 228
  - sweet, 228
  - Turkish, 228
  - wild, 228
- Chestnut, 207, 208, 226
  - European, 226
  - oak, 224
- Chicory, 271
- Chin-pat, 84
- Chinese paper, 120
- Chloroform test for wheat and rye flour, 347
- *Chlorogallum pomeridianum*, 269
- *Chlorophora tinctoria*, 244
- Chlorophyl grains, 29
- Chloroplasts, 29
- *Chloroxylon Swietenia*, 242
- Chlorzinc iodine, 22
- Chromatic aberration of objectives, 6
- Chromic acid, 21
- Chrysanthemin, 313
- *Chrysanthemum Cinerariæfolium*, 310, 311
  - *Leucanthemum*, 323
  - *Marschallii*, 310, 311

Chrysanthemum roseum, 310, 311
Chrysotile, 156, 157
Chumese, 84
Cichoriaceæ, 273
Cichorium Intybus, 50, 271
Cigar-box wood, 219
Cistus salvifolius, 301
Citric acid, microchemical tests for, 448
Citrus fruits, 327
Closed bundle, 259
    syncarps, 327
    teeth, 421
Cloves, 310
Cochineal, 23
Cockle, 349
Cocoanut, 327
    cake, 403
    palm, 243
Cocobola, 240
Cocos nucifera, 403
Cocos wood, 242
Cocus wood, 208, 242
Cœlococcus Carolinensis, 414
    Salomonensis, 414
Coffee, malt, 354
    nut, 220
    tree, Kentucky, 220
Cogwood, 241
Coleophyllum, 241
Collateral bundle, 264
Collodion, 57
Colonial mahogany, 241
Colored ebony, [illegible]
Combretaceæ, 400
Companion cells, [illegible]
Comparative crystal analysis, 440
Complementary cells, [illegible]
Compositæ, 313, 317, 327, 373
Composite bundles, [illegible]
Compound microscope, 3
    nut, 327
    stone fruit, 327
Concentric bundle, 264
Condenser substage, for compound microscope, 11, 13
Condori wood, [illegible]
Conducting cells, [illegible]
[illegible]
[illegible]
[illegible]
Coniferous woods, [illegible]
    parenchyma of, 193
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
Corallin, 23
Corchorus capsularis, 81
    olitorius, 81
Cordia, 240
Coriamyrtin, 309
Coriaria myrtifolia, 300, 304
    ruscifolia, 304
    thymifolia, 304
Cork, 274
    black, 275
    "female", 275
    in fig coffee, 296
    "male", 275
    oak, 226
    woods, 253
Corn starch, 40
Cornus, 208
Corolla of disc flowers, 318
Coromandel wood, 239
Corpuscles, bone, 420
Cortex of animal hairs, 123, 125
Cosmos fiber, 82
Cotinus, 295
    Coggygria, 229, 246, 300, 303
Cotton, 55
    American, 61
    Barbardos, 58
    Brazilian, 61
    dead hairs of, 64
    Egyptian, 60
    half-ripe hairs of, 64
    Indian, 61
    length of staple, 59
    mercerized, 65
    New Orleans, 58
    Peruvian, 61
    rag paper, 109
    Sea Island, 58, 60
Cottonseed cake, 361
    meal, 361
Cottonwood, 238, 239
    balsam, 239
    black, 239
Cotyledons, [illegible]
[illegible], 252
Cow hair, 133
    distinction of sheep's wool, goat's wool, and, 134
  wheat, [illegible]
Crack willow, [illegible]
[illegible]
Cratægus Oxyacantha, 207
Cremocarp, 327
[illegible]
Cross-cells, 327
    sections, [illegible]
    tracheids, [illegible]
Crotalaria juncea, 84
[illegible]
Crown cement of ivory, 426
Cruciferæ, [illegible]
Crystal analysis, comparative, 440
    individual, 443

Crystal fibers, 284
Crystals, 290
Cuba mahogany, 241
Cuban grenadilla wood, 242
    pine, 217
Cucumber tree, 231
Cucurbita maxima, 369
    moschata, 369
    Pepo, 369
Cucurbitaceæ, 327
Cuprammonia, 22
    action of, on cloth, 162
Cupressus, 176, 213
    sempervirens, 213
Cupuliferæ, 203
Curcuma starch, 46
Curcuma angustifolia, 46
    leucorrhiza, 46
    longa, 262
    rotunda, 262
Curcumin, 265
    action of
        ammonia on, 266
        boric acid on, 266
        concentrated hydrochloric acid on, 266
        concentrated sulphuric acid on, 266
        dilute sulphuric acid on, 266
        potash on, 266
        water on, 266
Curled birch, Swedish, 236
    mint, leaves, 309
Cuticle, 52, 280
Cuticular scales of animal hairs, 123, 125
Cutin, 280
Cycadaceæ, 48
Cycas, 47
Cyperaceæ, 298
Cyperus Papyrus, 122
Cypress, bald, 215
    black, 215
    common, 213
    Lawson's, 213
    red, 215
    white, 215
Cystoliths, 53

Daisy, ox-eye, 323
Dalbergia, 240
    melanoxylon, 242
Dalmatian insect powder, 310
Daphne cannabina, 122
Daphne fiber paper, 122
Darnel, 349
Date palm, 243
Deer antlers, 421
Dehiscent fruits, 326
Dentine canals, 421
    of ivory, 423
    teeth, 421
Dermatogen, 290
Desert fir, Japanese, 212
Dextrine, 35
Diaphragm, iris, for compound microscope, 11
Diaphysis, 418
Diastase, 36
Dicotyledonous rhizomes, 268
    roots, 268
Dicotyledons, 333
    wood of, 174
Dioscorea elata, 47
    sativa, 47
Diospyros, 221
    Ebenum, 239
    hirsuta, 239
    Virginiana, 222
Disc flowers, 311
Dissecting microscope, 4
Distinction between sheep's wool, goat's wool, and cow hair, 134
Dogwood, 208
Domingo mahogany, 241
Douglas fir, 215
Drupe, 326
    syncarpous, 327
Duckweed, 326
Duramen, 207
Dwarf sumach, 300
Dyers' pastel, 309
    weed, 309
    woad, 309
Dyes, 23
Dyewoods, 243

Eagle wood, 242
East India arrowroot, 46
    Indian satinwood, 242
Ebony, 208, 239
    Ceylon, 239
    colored, 239
    green, American, 242
    Macassar, 239
    Mauritius, 239
    Orange River, 239
    Siam, 239
    streaked, 239
    Zanzibar, 239
Edgeworthia papyrifera, 121
Elæis Guineensis, 400
    melanococca, 400
Elder, black, 228
Elephas Africanus, 422
    Indicus, 422, 423
    primigenius, 422
Elm, 208
    European, common, 222
    field, 222
    red, 222
    rock, 222
    water, 222
    white, 222, 223
    yoke, 232
Embryo, 333

Emergence, 52
Emmer, 334
Enamel of teeth, 421
Endocarp, 328
Endodermis, 264, 280
Endosperm, 31, 331
English wheat, 334
Entada, 327
Epicarp, 328
Epidermis, 261
    of animal hairs, 123, 125
    of leaves, 302, 303, 307, 316, 318, 319, 322
Epiphyses, 416
Ergot, 349
Erica arborea, 235
Eriodendron anfractuosum, 68, 368
Erythrina acanthocarpa, 253
    Crista galli, 255
Esparto cellulose paper, 110
Ether, 23
Eucalyptus, 241
Euclea pseudebenus, 239
Euphorbiaceae, 45, 273
European birch, white, 236
    chestnut, 226
    elm, common, 222
    fir, 212
    walnut, 230
Evergreen oak, 226, 275
Evonymus, 208, 235
    Europaea, 235
Examination of flour, 342
Examples, practical, [illegible]
Excretion cavities, [illegible]
Exine, 315
Exocarp, 328
Extract wool, [illegible]
Eyepieces, see Oculars

Fabrics, figured, 158
    fineness of weave, [illegible]
    [illegible]
    [illegible]
    [illegible]
    woolen, examination of, [illegible]
        [illegible]
[illegible]
[illegible]
    [illegible]
    [illegible]
    [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible] manufacture of wheat
    [illegible]
[illegible]
    [illegible]
    [illegible]
    [illegible]

Fiber, paper mulberry, 92
    rhea, 90
    roa, 92
    sinew, 150
Fibers, animal, 123
    bast, 284
    crystal, 284
    mineral, 123, 156
    of dicotyledonous plants, 7
        monocotyledonous plants
        stems, 72
    substitute, 206
    true wood, of broad-leaved wo
        196
    vegetable, 51
Fibroin of silk, 144
Fibro-vascular bundles, 72, 258, 259
Field elm, 222
    maple, 207, 233
Fig, 325
    coffee, containing cork, 296
Figured fabrics, 158
Fir, 196, 207
    balsam, 212
    Douglas, 215
    European, 212
    Japanese desert, 212
    red, 215
    riga, 216
    Scotch, 216
    silver, 212
    spruce, 215
    Swedish, 216
    white, 212
    wood, medullary rays of, 186
    yellow, 215
Flax, [illegible]
    New Zealand, 99
Flecks, pith, [illegible]
Flores [illegible] *citrinae*, 323
Floss of silk cocoon, 144
Flour, ash of, 345
    color of, 343
    examination of, 342
    mechanical condition of, 343
    microscopy of, 346
Flower heads, organs of, 313
Flowers, [illegible]
    orange, 310
    parts of, 310
Follicle, [illegible]
Formic acid, microchemical tests for, 448
Fossil ivory, 422
Fourcroya, [illegible]
    Cubensis, 97
    foetida, 97
    gigantea, 97
Frangula, 208
Fraxinus, 220
    Americana, 221
    excelsior, 221
    nigra, 221
    Oregona, 221

Fraxinus Pennsylvanica, 221
var. *lanceolata*, 221
pubescens, 221
quadrangulata, 221
Sambucifolia, 221
viridis, 221
Fruit, 324
accessory, 325
aggregate, 325
anthocarpous, 325
coat, 328
multiple, 325
stone, 326
compound, 327
Fruits and seeds, 324
Beck's classification of, 326
classification of, Beck's, 326
compound, 326
consolidated, 327
dehiscent, 326
indehiscent, 326
kinds of, 324
morphology of, 324
multiple, 327
simple, 326
Fuchsin, 23
Funiculus, 329
Fuse, identification of, used by incendiary, 159
Fusion tests, microchemical, 441
Fustic, 208
distinction of old from young, 249
old, 244, 249
young, 229, 246, 249
identification of, 295

Galium, 327, 349
Gambo hemp, 83
Gampi fiber, 122
Gelatin silk, 156
Georgia pine, 217
German broom, 85
Ghore sun, 84
"Gidden", 150
Ginger, 266
pine, 213
Gipsy oak, 225
Glans, 327
Globuli of teeth, 421
Glucase, 36
Gluten, 340
cells, 339
Glycerine, iodine, 22
Goat-willow, 238
Goat's wool, 130
Angora, 130
Cashmere, 131
common, 132
distinction of sheep's wool cow hair, and, 134
mohair, 130
Thibet, 131
Gold, microchemical tests for, 446
Gomuti palm, 243
Gonostylus, 243
Gossampinos rubra, 368
Gossypium, *arboreum*, 58
Barbadense, 58, 361
herbaceum, 58, 361
hirsutum, 58
religiosum, 58
Taitense, 59
Grain of wood, 177
Gramineæ, 298
Granadilla wood, 242
Granulose, 33
Grape, 327
vine, 227
Gray willow, 204
Greek sumach, 300
Green ash, 221
ebony, American, 242
Havana wood, 241
Greenheart, 240
Grenadilla wood, 242
African, 242
Cuban, 242
Ground olive stones, 371
detection of, in pepper, 374
tissue, 260
Guajacum officinale, 240
Guard cells, 298
Guiana arrowroot, 47
Guilloching of ivory, 425
Guimara, 95
Guizotia Abyssinica, 375
oleifera, 375
Gum, black, 234
sour, 234
Guncotton, 57
Gun wad, identification of, 160
Gymnocladus, 220
Canadensis, 220
dioicus, 220
Gymnosperms, wood of, 174
Gynæceum, 313, 324
Gysophila Arrostii, 270
paniculata, 270
Struthium, 269

Hadromal, 102
Hadrome, 259
Hæmatein, 251
Hæmatoxylin, 23, 251
Hæmatoxylon campecheanum, 251
Hair, calf, 134
camel's, 137
cow, 133, 134
Hairs, vegetable, 51
Halle process for manufacture of wheat starch, 39
Hard maple, 233
pine, 217
woods, 213

Hard woods, examples of, 208
Hardness of wood, 208
Harst beech, 232
Havers' canals, 419
Hayti mahogany, 241
Hazel, 207
Heart ripewood, 208, 222
Heartwood, 207
Heckling, 73
Hedgehog wheat, 334
Helianthus annuus, 377
  tuberosus, 50
Helichrysum arenarium, 323
Hemicellulose, 55
Hemlock, 212, 287
Hemp, 77
  bast, 77
  Bombay, 84
  brown, 84
  cake, 395
  Calcutta, 84
  Conkanee, 84
  gambo, 83
  Indian, 84
  Madras, 84
  Mauritius, 97, 100
  paper, 108
  pita, 90
  pure, 77
  sisal, 90
  sunn, 84
[illegible]
[illegible]
Herzberg's test for identification of fibers in paper, 104
[illegible]
Hibiscus cannabinus, [illegible]
Hickory, [illegible]
  pignut, [illegible]
  shagbark, [illegible]
  shellbark, [illegible]
[illegible]
  [illegible]
  [illegible]
  [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
  [illegible]
[illegible]
  [illegible]
  [illegible]
  [illegible]
  [illegible]
[illegible]
  [illegible]
  [illegible]
  [illegible]
Horn, refuse, 430
  sheep, 430
  teeth, 421
Hornbeam, 207, 208, 232
  hop, 236
Hornblende asbestos, 156
Horny prosenchyma, 288
Horse-chestnut, 204, 208, 237
  starch, 33
Horst beech, 232
Hour-glass weed, 323
Huanaco, 139
Hummel silk, 152
Humulus lupulus, 87
Hungarian bird's-eye maple, 23[illegible]
  oak, 225
  yellow wood, 246
Hydrocellulose, 57
Hydrochloric acid, 21
Hymenaea Courbaril, 242
Hypanthodia, 328
Hypocotyl, 333
Hyoscyamus, 326

Illuminating apparatus of compound microscope, 8, 9
Incense cedar, 214
  wood, 209
Indian hemp, 84
Indigofera, 300
Individual crystal analysis, 443
Inga vera, 242
Insect powder, 310
  Caucasian, 323
  Dalmatian, 310
  Persian, 310
Integuments, [illegible]
Interfascicular cambium, 291
  wood, 291
Interglobular spaces of teeth, 421
[illegible]
[illegible]
[illegible]
[illegible]
Iodine, chlorzinc, 22
  glycerine, 22
  solution, 22
    aqueous, 22
    in potassium iodide, 22
  tincture, 22
[illegible]
Iris diaphragm for compound microscope, [illegible]
[illegible]
  [illegible]
  [illegible]
  [illegible]
Ironwood, 206, 222, 236
[illegible]
[illegible]
[illegible]
  [illegible] lines of, 424
  [illegible] lines of, 424

Ivory, crown cement of, 426
    dentine canals of, 423
    fossil, 422
    guilloching of, 425
    hippopotamus, 426
    Indian, 423
    mammoth, 422
    narwhal, 428
    nut, 412
    Schreger lines of, 425
    sperm-whale, 428
    true, 422
    vegetable, 412
    walrus, 427

Jacaranda Brasiliana, 241
Jamaica mahogany, 241
Japanese desert fir, 212
    nutmeg wood, 236
    paper, 120
Javelle water, 21
Jointed apocarp, 326
    latex tubes, 273
    pod, 327
Jointless latex tubes, 273
Juglans, 202, 207, 230
    cinerea, 230
    nigra, 230
    regia, 208, 230
Juniper, 208
    berry, 328
    common, 214
    savin, 214
Juniperus, 176, 213
    communis, 214
    Virginiana, 189, 214
Jute, 81
    paper, 109

"Kaffir marble cork", 253
Kapok cake, 368
    East Indian, 368
    Java, 368
Kemps, 128
Kentucky coffee-tree, 220
Keratin, 429
Kermes oak, 226
Key, Burgerstein's analytical, for spruce and larch woods, 192
    analytical, for identification of economic woods, 211
Khaya Senegalensis, 241
King wood, 241
Kopra, 403

Labarraque solution, 21
Laguna mahogany, 241
Laine artificielle, 82
Lamella, cellulose, 279
    middle, 180, 279
    outer, 180
    suberin, 279
Langhans silk, 152
Laportea Canadensis, 90
Larch, 190, 208, 216
    and spruce woods, Burgerstein's analytical key for, 192
    medullary rays of, 190
Larix, 216
    decidua, 216
    Europæa, 216
    occidentalis, 216
Larkspur, 326
Latex, 274
    tubes, 273
        jointed, 273
        jointless, 273
Laurus Sassafras, 268
Lawson's cypress, 213
Lead nitrate and saltpeter, fusion test, 441
Leaf, blade of, 324
    sheath of, 324
Leaves, 29, 297
    balm, 309
    bifacial, 29
    centric, 29
    curled mint, 309
    isolateral, 29
    patchouli, 309
    peppermint, 309
    rosemary, 309
Legume, 326
Leguminosæ, 242, 251, 253
Leguminous starches, 48
Lehner silk, 152, 156
Lens holder, 4
Lenticels, 276, 282
Lentil starch, 49
Leopard-wood, 239
Letter-wood, 239
Leucoplasts, 31
Levantine soapwort, 269
Libocedrus, 213
    decurrens, 214
Libriform cells, 197
Lign-aloes, 242
Lignin, 58, 101
    tests for, 102
Lignum-vitæ, 207, 208, 240
Ligustrum, 208
Liliaceæ, 269
Lima wood, 252
Lime tree, 234
Linden, 207, 208
    American, 234
    small-leaved, 234
    summer, 234
    winter, 234
Linen cloth containing tow yarn, 161
    rag paper, 107
    yarn, 77
Linseed cake, 384
    meal, 384
Linum usitatissimum, 73
Liriodendron, 230
    tulipifera, 231, 293

Live oak, 224
Llama, 139
Loblolly pine, 217
Locust, 208
    black, 220
Logwood, 251
Lolium temulentum, 349
Loment, 327
Long-leaved pine, 217
Longwort, 269
Lonicera, 327
Lupis, 95
Lygeum Spartum, 111
Lysigenous cavity, 194

Macaroni wheat, 334
Macassar ebony, 239
    sandalwood, 240
Machærium Schomburgkii, 239
Maclura tinctoria, 244
Maclurin, 246
Macrochloa tenacissima, 111
Madia cake, 377
Madia sativa, 377
Madras hemp, 84
Mahaleb cherry, 228
Mahogany, 207, 241
    arena, 241
    bastard, 241
    birch, 236
    Cape, 241
    Colonial, 241
    Cuban, 241
    Domingo, 241
    Hayti, 241
    Honduras, 241
    Jamaica, 241
    Laguna, 241
    Porto Plata, 241
    Tabasco, 241
    Yucatan, 241
Maize husk paper, 112
    starch, 33, 40
Malabar arrowroot, 40
"Male" cork, 275
[illegible], 281
Malt coffee, 354
Maltose, [illegible]
[illegible]
    [illegible], 237
[illegible]
[illegible], 48
[illegible]
[illegible], 45
Manila hemp, [illegible]
    [illegible]
Maple, [illegible]
    [illegible] bird's-eye, 234
    [illegible], 233
    [illegible], 233
    [illegible], 233
    [illegible], 233
    Hungarian bird's-eye, 234
Maple, Norway, 207, 233
    plane, 233
    red, 233
    rock, 233
    Russian bird's-eye, 234
    sugar, 233
    swamp, 233
    sycamore, 233
Maranta arundinacea, 33, 43
    Indica, 43
Maranta starch, 43
Marrow canals of horn, 430
    of tortoise shell, 434
    of whalebone, 437
Marsdenia, 70
Martin process for manufacture of wheat starch, 37
Mauritius ebony, 239
    hemp, 97, 100
Mazard cherry, 228
Mechanical stage for compound microscope, 16
    wood pulp, 116
Mechanico-microscopical analysis
  of barley groats containing millet bran, 358
  of genuine and false barley groats, 357
  Weinzierl's method of, 354
Medicago, 142
Medlar, 236
Medulla of animal hairs, 123
Medullary coefficient, Schröder's, 191
    rays, 176, 184
        cells of, 203
        of broad-leaved woods, 196
        of fir wood, 186
        of larch, 190
        of pine wood, 187
        of red cedar, 189
        of spruce wood, 186
        primary, 184
        secondary, 184
    repetitions, 205
[illegible], 435
Melampyrum arvense, 349
Mercuric chloride, 22
Mercury, [illegible]
[illegible], 295
[illegible]
[illegible]
Mespilus, [illegible]
    germanica, 236
Metarabic acid, [illegible]
Methyl green, [illegible]
    violet, [illegible]
Methylene blue, [illegible]
[illegible]
[illegible]
Microchemical analysis, 430
    mixture tests, 442
    tests for aluminium, 443
        for barium, 444

Oak, bitter, 225, 281
  black, 224, 281
  British, 224, 281
  bur, 224
  central European species, 224
  chestnut, 224
  common, 224
  cork, 226
  evergreen, 226, 275
  gipsy, 225
  Hungarian, 225
  kermes, 226
  live, 224
  Mediterranean species, 225
  North American species, 223
  over-cup, 224
  red, 224
  Spanish, 275
  swamp white, 224
  tan bark, 224, 281
  Turkey, 225
  white, 224
Oaks, central European, 224
  North American, 223
  Mediterranean, 225
Oat starch, 43
Objectives, 6, 11
  angular aperture of, 11
  chromatic aberration of, 6
  numerical aperture of, 12
  spherical aberration of, 6
Ochroma lagopus, 68, 255
Ocotea caudata, 243
Oculars or eyepieces of compound microscope, 7, 13
Ohio buckeye, 238
Oil-cake meals, 350
Oil-cakes, 355
  and oil-cake meals:
    methods of examination of, 350
    microscopical examination of, 360
    preliminary test of, 350
    processes of manufacture of, 350
    sampling of, 360
Oil-seed meals, 350
Old field pine, 217
  fustic, 244, 245
    distinction of, from young fustic, 245
Olea, 255
  Europaea, 255, 371
Olive stones, ground, 371
  tree, 255
One-grained wheat, 34
[illegible]
Oosphere, 332
Open bundles, 259
  teeth, 427
Optical separation of millet-flour and millet-chaff, 350
Orange flowers, 310
  River ebony, 239
Oregon ash, 221
  cedar, 213
  pine, 215
Organs, subterranean, 262
"Ori", 323
Orris root, 266
Orthotropous ovule, 329
Ossein, 418
Osteodentine, 423
Ostrya, 235
  Virginica, 236
Outer lamella, 180
Over-cup oak, 224
Ovule, 329
  anatropous, 329
  atropous, 329
  campylotropous, 330
  orthotropous, 329
Ox-eye daisy, 323
Oxycellulose, 57

Padouk, 242
Palisade parenchyma, 306
Palisander, 241
Palm, cocoanut, 243
  date, 243
  Gomuti, 243
  -nut cake, 400
  Palmyra, 243
  wood, 243
    black, 243
    white, 243
Palmæ, 255
Palmyra palm, 243
  wood, 243
Panicum miliaceum, 393
Papaveraceæ, 272
Paper, adansonia, 122
  bamboo sprout, 122
  birch, 120
  Chinese, 120
  cotton rag, 109
  Daphne fiber, 122
  esparto cellulose, 110
  hemp, 108
  Herzberg's test for identification of fibers in, 104
  v. Höhnel's test for identification of fibers in, 105
  identification of fibers in, 104
  Japanese, 120
  jute, 106
  linen rag, 107
  maize husk, 112
  Manila hemp, 122
  microscopic examination of, 100
  millet straw, 114
  mulberry fiber, 92
  mulberry paper, 121
  Nepal, 122
  paper mulberry, 121

- Paper, pita hemp, 122
  - rye-straw cellulose, 110
  - sizing of, 103
  - straw cellulose, 110
  - sugar-cane, 119
  - tree-bast, 122
  - wheat-straw cellulose, 110
- Papers, miscellaneous, 122
- *Papilionaceæ*, 84, 253
- Pappus, 313, 316
- Papyrus, 122
- Parchment of silk cocoon, 144
- Parenchyma, palisade, 306
  - spongy, 306
  - true, 283
  - wood, 176, 193, 206
    - of broad-leaved woods, 196
- Partridge wood, 242
- Patchouli leaves, 309
- Pauly silk, 156
- Pea starch, 49
- Peach, 326
- Peanut cake, 387
- Pear, 207, 208, 237
- Peduncle, 322
- Pentoses, 55
- Peony, 326
- Pepo, 327
- Pepper, detection of ground-olive stones in, 374
- Pepperidge, 234
- Peppermint leaves, 309
- Periblem, 290
- Pericarp, 228, 326
- Periderm, 263, 282
- Pernambuco Brazil wood, 252
- Persian insect powder, 310
- Persimmon, 222
- Petiole, 324
- Pferdefleischholz, 241
- Pheasant wood, 242
- Phelloderm, 276, 282
- Phellogen, 276, 282
- Phellonic acid, 279
- Phenogams, 333
- Phloem, 259
- Phloroglucin, 23
- *Phormium tenax*, 99
- Photosynthesis, 29
- *Physalus antiquorum*, 435
- *Physeter macrocephalus*, 422, 428
- Physico-technical properties of woods, 207
- *Physocalymna scaberrimum*, 240
- *Phytalephas macrocarpa*, 412, 415
- *Picea*, 175, 215
  - *alba*, 216
  - *Canadensis*, 216
  - *Engelmanni*, 216
  - *excelsa*, 215, 216
  - *Mariana*, 216
  - *nigra*, 216
  - *rubens*, 216
- *Picea rubra*, 216
- Picric acid, 21
- Pig-nut hickory, 221
- Piled fabrics, 158
- Pine, 187, 216
  - black, 217
  - bull, 217
  - Cembra, 218
  - Cuban, 217
  - Georgia, 217
  - ginger, 213
  - hard, 217
  - loblolly, 217
  - long-leaved, 217
  - medullary rays of, 187
  - mountain, 217
  - North Carolina, 217
  - Norway, 217
  - old field, 217
  - Oregon, 215
  - riga, 208, 216
  - Scotch, 187, 188, 216
  - short-leaved, 217
  - Siberian stone, 218
  - slash, 217
  - Southern, 217
  - stone, 188
  - sugar, 218
  - Swiss, 218
  - Weymouth, 218
  - white, 188, 218
  - wild, 216
  - yellow, 217
- Pineapple, 327
- "Pinkos" tubers, 213
- *Pinna nobilis*, 149
- *Pinus*, 176, 188, 216
  - *Australis*, 217
  - *cedrus*, 208
  - *Cembra*, 188, 216, 218
  - *Cubensis*, 217
  - *echinata*, 217
  - *halepensis*, 288
  - *Lambertiana*, 216, 218
  - *Laricio*, var. *Austriaca*, 217
  - *mitis*, 217
  - *Montana*, 217
  - *mughus*, 217
  - *nigra*, 187, 217
  - *nigricans*, 217
  - *palustris*, 217
  - *pinaster* var. *Austriaca*, 217
  - *ponderosa*, 217
  - *Pumilio*, 217
  - *resinosa*, 217
  - *silvestris*, 184, 187, 208, 216, 218
  - *strobus*, 188, 216, 218
  - *Tæda*, 217
- *Pipturus argenteus*, 92
- *Piratinera Guayanensis* 239
- *Pirus*, 237
  - *communis*, 237
  - *Malus*, 237

Pistacia lentiscus, 301
Pistil, 313, 324
Pita hemp, 96
    paper, 122
Pith, 206
    flecks, 205
    rays, 176
Pits, 180
    bordered, 179, 181
    simple, 181
Pitted vessels, 199
Pittosporum, 241
Placenta, 329
Plain fabrics, 158
Plane maple, 233
    tree, 208
        American, 230
Platanus, 208, 230
    occidentalis, 230
Plates, sieve, 259
Plerom, 290
Plum, 207, 208, 228
Plumule, 34, 333
Pocket-lens, 4
Pod, bordered, 327
    jointed, 327
Polarization apparatus, 15
Polish wheat, 334
Pollen grains, 314
Polycarps, 327
Polygonum Convolvulus, 349
Pomaceæ, 235
Pomegranate, 327
Poplar, 208, 238
    black, 239, 275
    trembling, 238
    white, 208, 239
    yellow, 231
Poppy, 326
    cake, 393
Populus alba, 239
    Canadensis, 238
    deltoidea, 238
    Fremontii, 239
    grandidentata, 238
    monilifera, 238
    nigra, 239, 275
    tremula, 238, 293
    tremuloides, 238
    trichocarpa, 239
Pore capsule, 326
Pores, 180, 298
    water, 299
Port Orford cedar, 213
Porto Plata mahogany, 241
Portuguese sumach, 300
Potassium bichromate, 22
    hydrate, 21
    iodide and silver iodide, fusion test, 442
    microchemical tests for, 447
Potato starch, 27, 33, 36
Powder, insect, 310
Practical examples, 159, 293
    action of cuprammonia on cloth, 162
    cork in fig coffee, 296
    distinction of dyed wool from wool of black sheep, 166, 168
    distinction of moth holes from holes caused by burning, 171
    examinations of woolen fabrics, 163, 164, 165, 166, 168
    fineness of weave of fabrics, 170
    identification of covering of telephone wires, 171
    identification of fuse used by incendiary, 159
    identification of gun wad, 160
    identification of ramie yarn, 161
    identification of snare cord, 159
    identification of wood used for pulp, 293
    identification of young fustic, 295
    imitation Spanish cedar, 295
    linen cloth containing tow yarn, 161
    materials used for racket strings, 172
    red sandalwood as an adulterant of spices, 296
    sawdust in foods, 295
    starch in wood as a means of determining the time of felling, 295
Primary medullary rays, 184
    wood, 178
Primavera wood, 241
Privet, 208
Procambium, 259
Prosenchyma, horny, 288
Proteaceæ, 326
Provençal sumach, 300
Prunus, 227
    Armeniaca, 228
    avium, 228
    Cerasus, 228
    domestica, 228
    insititia, 228
    Mahaleb, 228
    Padus, 229

Prunus serotina, 228, 233
Pseudocarps, 325
Pseudotsuga, 215
  Douglasii, 215
  mucronata, 215
Ptæroxylon, 241
Pterocarpus Indicus, 239
  santalinoides, 252
  santalinus, 252
  saxatilis, 239
Pumpkin-seed cake, 369
Purple Heart, 242
  wood, 242
Pyrethrosin, 313
Pyrethrotoxic acid, 313
Pyrethrum carneum, 310
  roseum, 310
Pyxis, 326

Quaking asp, 238
Quebracho, 208
Queensland arrowroot, 46
  rosewood, 240
Quercus, 223
  alba, 224
  bicolor, 224
  Cerris, 222, 225, 281
  coccifera, 226
  conferta, 225
  Ilex, 226, 275, 304
  lanuginosa, 281
  lobata, 224
  lyrata, 224
  macrocarpa, 224
  occidentalis, 275
  pedunculata, 224, 281
  platanoides, 224
  Pseudosuber, 275
  pubescens, 281
  robur, 224, 225, 281
  rubra, 224
  sessiflora, 224, 225, 281
  suber, 226, 275
  virens, 224
  Virginiana, 224
Quillai bark, 288
Quillaja Saponaria, 288

Racket strings, materials used for, 172
Radial bundle, 264
  sections, 175
Radicle, 333, 341
Radish, 327
Radix Anchusæ luteæ, 269
  Saponariæ rubræ, 269
Ramie, 90
  yarn, identification of, 161
Rape cake, 392
Raphanus Raphanistrum, 392
Raphe, 330
Rare woods, 242
Rattan, 243, 255
Rays, bark, 285
Rays, medullary, 176, 184
    cells of, 203
    of broad-leaved woods, 196
  pith, 176
Reagents, 19, 21
  for specific reactions, 22
Receptacle, 322
Red ash, 221
  beech, 197, 207, 232
  cedar, 189, 214
    medullary rays of, 189
  coral wood, 242
  cypress, 215
  elm, 222
  fir, 215
  Havana wood, 242
  maple, 233
  mulberry, 220
  oak, 224
  sandalwood, 252
    in spices, 296
  saunders, 252
  spruce, 216
  wood, 215, 242, 252
    African, 252
  woods, 252
Redoul, 304
Reseda luteola, 309
Respiratory cavity, 298
Retting, 73
Rhamnus, 229
  cathartica, 229
  Frangula, 229
Rhea fiber, 90
Rhizomes, dicotyledonous, 268
  monocotyledonous, 262
Rhizophora Mangle, 281
Rhus copallina, 300
  Coriaria, 300, 301, 303
  Cotinus, 229, 246, 300
  glabra, 300
  typhina, 300
Rice, chaff of, 351
  starch, 33, 42
Riga fir, 216
  pine, 208, 216
Ring, mixed, 284
  sclerenchyma, 284
Rings, annual, 175, 203
Ripewood, 207
Rippling, 73
Roa fiber, 92
Robinia, 208, 220
  pseudacacia, 220
Rock elm, 222
  maple, 233
Root, alkanna, 269
  orris, 266
  sassafras, 268
  teeth, 421
Rootless teeth, 421
Roots, 174

Roots, dicotyledonous, 268
    monocotyledonous, 262
Rose, 326
Rosemary leaves, 309
Rosewood, 240, 241
    African, 240
    Brazilian, 240
    Queensland, 240
    West Indian, 240
Rumex hymenosepalum, 269
Russian bird's-eye maple, 234
Rye starch, 33
Rye-straw cellulose paper, 110

Safflower, 310
Saffron, 310
Sago starch, 33, 47
Sagus farinifera, 47
    lævis, 47
    Rumphii, 33, 47
Salicaceæ, 237
Salix alba, 238
    Caprea, [illegible], 238
    fragilis, [illegible], 238
Sallow, [illegible]
Salmalia Malabarica, 368
[illegible] nut, [illegible]
Saketti, 84
Saltpeter and lead nitrate, fusion test, [illegible]
Samara, [illegible]
Sambucus, [illegible]
    nigra, [illegible]
Sampling oil-cakes and oil-cake meals, [illegible]
Sandalwood, African, [illegible]
    Macassar, [illegible]
    red, [illegible]
    [illegible]
    white, [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible] flour, [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

Sclerenchyma ring, mixed, 284
Scorza rossa, 288
Scotch fir, 216
    pine, 187, 188, 216
Scutching, 73
Scutellum, 341
Sea silk, 149
Secondary medullary rays, 184
    wood, 178
Secretion cavities, 193
    cells, 265
Sections, cross, 175
    radial, 175
    tangential, 175
    transverse, 175
Seed, 329
    coat, 333
Sequoia, 215
    gigantea, 215
    sempervirens, 215
    Wellingtonia, 215
Sericin of silk, 144, 145
Serpentine asbestos, 156
Service tree, 237
Sesame cake, 380
Sesamum Indicum, 380
    orientale, 380
    radiatum, 380
Shagbark hickory, 222
Sheath of leaf, 324
Sheep, breeds of, 124
Sheep's wool, 124
    abnormal hairs in, 129
    beard hairs of, 129
    [illegible] in, 128
    coloring of, 129
    cortex of, 125
    cuticular scales of, 125
    distinction of goat's wool, cow hair, and, 134
    epidermal cells of, 125
    fineness of, 127
    kemps of, 128
    number of scales of, 126
[illegible]
Shellbark hickory, 222
Shoddy, [illegible]
    absence of epidermal scales in, [illegible]
    appearance of ends of fibers of, [illegible]
    diameter of fibers of, 142
    fibers of many colors in, 143
    foreign fibers of, 140
    length of fibers of, 142
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
    [illegible]
[illegible]
Silk, action of Fehling solution on, 155

Silk, ailanthus, 148
  and silk substitutes, 144
  artificial, 151
  baves of, 144
  Chardonnet, 155
  cocoon, floss of, 144
    middle layer of, 144
  color with Millon's reagent, 155
  common, 144
  fibroin of, 144, 145
  sea, 149
  sericin of, 144, 145
  treatment with iodine in potassium iodide, 155
  tussah, 148
  wild, 148
  yamamai, 148
Silver fir, 212
  iodide and potassium iodide, fusion test, 442
Simple berry, 326
  bundles, 258
  fruits, 326
  microscope, 4
  pit, 181
  stone fruit, 326
Sinew fiber, 150
Sisal hemp, 96
Skewer wood, 235
Slash pine, 217
Small-leaved linden, 234
Smooth sumach, 300
Smut spores, 349
Snake wood, 239
Snare cord, identification of, 159
Soapwort, 269
  California, 269
  common, 270
  Levantine, 269
  white, 271
Soda cellulose, 118
Sodium, microchemical tests for, 447
Soft woods, 213
Solution tests, microchemical, 442
Sorbus, 205, 236
  Aria, 237
  torminalis, 237
Sour cherry, 228
  gum, 234
Southern pine, 217
Spanish broom, 85
  cedar, 219
    imitation, 295
  oak, 275
  sumach, 300
Spartium junceum, 85
  scoparium, 85
Specific reactions, reagents for, 22
Spelt, 334
Spermoderm, 333
Sperm-whale ivory, 428
Sphærites, 32
Spherical aberration of objectives, 6
Spices, red sandalwood in, 296
Spindle tree, 208
  wood, 235
Spiral vessels, 199
Spongy parenchyma, 306
Spores, smut, 349
Spring wood, 179
Spruce, 186, 207, 209, 215
  and larch woods, Burgerstein's analytical key for, 192
  black, 216
  fir, 215
  red, 216
  white, 216
  wood, medullary rays of, 186
Stage of compound microscope, 8
Staghorn sumach, 300
Stamens, 314
Stand of compound microscope, 8
Standard of compound microscope, 8
Starch, 27
  acorn, 33
  arrowroot, 33
  assimilation, 30
  banana, 47
  barley, 33, 38
  bean, 49
  buckwheat, 33, 42
  canna, 46
  cassava, 45
  cells, 265
  cellulose, 33
  chemical properties of, 33
  curcuma, 46
  formation of, 29
  gelatination of, 33
  horse-chestnut, 33
  in wood as means of determining time of felling, 295
  iodine reaction of, 34
  leguminous, 48
  lentil, 49
  maize, 33, 40
  oat, 42
  pea, 49
  potato, 27, 33, 36
    abnormal, 37
  reserve, 31
  rice, 33, 42
  rye, 33, 38
  sago, 33, 47
  sweet-potato, 46
  tapioca, 33
  transition, 31
  wheat, 33, 38
    abnormal, 40
    from sprouted grain, 40
    processes of manufacture of, 39
  yam, 47
Stegmata, 95
Stems, 174
  monocotyledonous, 255

Stigma, 324
Stipa tenacissima, 110
"Stock im Eisen", 190
Stomata, 298
    water, 299
Stone fruit, compound, 327
        simple, 326
    pine, 188
        Siberian, 218
Straw cellulose paper, 110
Strawberry, 326
Streaked ebony, 239
Streaks, cell, 205
Strobiles, 327
Strophanthus, 70
Style, 324
Suberin, 58, 263, 279
    lamella, 279
Substage condenser, 11, 15
Substitute fibers, 206
Subterranean organs, 262
Sugar-cane paper, 119
Sugar maple, 233
    pine, 218
Sulphite cellulose, 116, 118
Sulphuric acid, 21
        test for detection of foreign matter in ground pepper, 375
Sumach, 300
    American, 300
    dwarf, 300
    Greek, 300
    myrtle-leaved, 304
    Portuguese, 300
    Provençal, 300
    Sicilian, 301
    smooth, 300
    Spanish, 300
    staghorn, 300
    tanner's, 300
    Venetian, 240, 303
Summer linden, 234
    wood, [illegible]
Sunflower cake, [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

Syncarps, closed, 327
        schizocarpous, 327
Synconia, 328
Synergidæ, 331
Synergids, 331

Tabasco mahogany, 241
Tamarack, 216
Tamarind, 326
Tamarix Africana, 301
Tambinziran wood, 242
Tanbark oak, 224, 281
Tangential sections, 175
Tanner's sumach, 300
Tapioca starch, 33, 45
Taraxacum officinale, 50
Taxodium, 214
        distichum, 215
Taxus, 176, 212
        baccata, 183, 193, 212
        brevifolia, 213
Tchoumâ, 90
Tea, 309
Teak, 208
Teakwood, 229
        Brazilian, 242
Tecoma leucoxylon, 241
Tectona, 220, 229
        grandis, 229
Teeth, 421
    closed, 421
    crown of, 421
    dentine, 421
    enamel of, 421
    horn, 421
    neck of, 421
    open, 421
    pulp of, 421
    root of, 421
    rootless, 421
Tegmen, [illegible]
Telephone wires, identification of covering, 171
Tellicherry arrowroot, 46
Terminalia Chebula, 406
Test, alcohol-hydrochloric acid, for flour, [illegible]
    alcoholic naphthylene blue, for flour, [illegible]
    [illegible] for gluten, 346
    chloroform, for wheat and rye flour, [illegible]
    Schimper's foam, for flour, 348
Testa, [illegible]
Tests for detection of foreign matter in pepper, 374, 375
    for [illegible]
    [illegible] microchemical, 441
Textile fibres, microscopic examination of, [illegible]
Textiles, [illegible]
Timber, [illegible]
    wood, [illegible]

Thorn, white, 207
Three-leaf twill, 158
Thuja, 176, 213
    gigantea, 214
    occidentalis, 214
Thymelæaceæ, 121
Tiger-wood, 239
Tik, Tiker or Tikor arrowroot, 46
Tilia Americana, 234
  parvifolia, 234
  platyphyllos, 234
Tipula, 205
Tissue, ground, 260
Tobacco, 309
Tooth cement, 421
Tortoise shell, 433
Torus, 181
Tow, 73
  yarn, 78
    in linen cloth, 161
Tracheæ, 199
    of broad-leaved woods, 196
Tracheids, 179, 259
    cross-, 186
    of broad-leaved woods, 196
Transverse sections, 175
Tree, heartripewood, 208
  heartwood, 207
  ripewood, 207
  sapwood, 207
Tree-bast paper, 122
Trembling poplar, 238
Trichechus Rosmarus, 422, 427
Trichomes, 51
Triticum monococcum, 334
    Polonicum, 334
    sativum compactum, 334
      dicoccum, 334
      durum, 334
      spelta, 334
      turgidum, 334
      vulgare, 334
Tropical broad-leaved woods, 206
True parenchyma, 283
  wood fibers of broad-leaved woods, 196
Tsuga, 212
  Canadensis, 212
Tube cells, 338
  of compound microscope, 9
Tubes, latex, 273
  sieve, 259
Tulip wood, 231, 240
Tupelo, 234, 253
Tupos, 95
Turkey oak, 225
Turkish boxwood, 241
    cherry, 228
Turmeric, 262
Tussah silk, 148
Twill, Batavia four-leaf, 158
  three-leaf, 158
Twilled fabrics, 158
Tyloses, 200

Ulmus, 203, 222
    Americana, 222
    Campestris, 222
      α-glabra, 222
      β-suberosa, 222
    effusa, 223
    fulva, 222
    racemosa, 222
    Thomasi, 222
Umbelliferæ, 327
Urtica cannabina, 90
  dioica, 88
Urticaceæ, 88, 92, 273
Utricle, 326
Uva, 327

Vacapow wood, 242
Vanillin, 101
Vascular bundles, 259, 307
    scheme, 292
Vegetable down, 68
    fibers, 51
    ivory, 412
    silk, 70
Venetian sumach, 246, 303
Vessels, 199, 259
    of broad-leaved woods, 196
    pitted, 199
    spiral, 199
Vetch, 326
Vicuña, 139
Vine, grape, 227
Violet wood, 208, 209, 240, 241
Viscoid, 57
Vitis, 227
  vinifera, 227
Vivier silk, 152

Wacapow wood, 242
Walnut, 207, 208, 327
    black, 230
    European, 230
    white, 230
Walrus ivory, 427
Warp, 157
Water elm, 222
    pores, 299
    stomata, 299
Wax, 261
Weed, dyers', 309
    yellow-moth, 323
Weinmannia glabra, 281
Weinzierl's method of qualitative and quantitative mechanico-microscopical analysis, 354
Weld, 309
West Indian boxwood, 241
      rosewood, 240
      satinwood, 242
Weymouth pine, 218
Whalebone, 435

Wheat, 333
- chaffy, 334
- cow, 349
- English, 334
- hedgehog, 334
- macaroni, 334
- naked, 334
- one-grained, 334
- Polish, 334
- starch, 33
- -straw cellulose paper, 110

White alder, 231
- ash, 221
- beam tree, 237
- birch, 236
  - European, 236
- cedar, 213, 214
- cypress, 215
- elm, 222, 223
- fir, 212
- mulberry, 220
- oak, 224
  - swamp, 224
- palm wood, 243
- pine, 188, 218
- poplar, 208, 239
- sandalwood, 209, 240
- soapwort, 271
- spruce, 216
- thorn, 207
- walnut, 230
- willow, 238
- wood, 231

[illegible], 122

Wild cherry, 228
- pine, 217
- silks, 148

Willow, 208
- brittle, 238
- crack, 238
- gray, 224
- white, 238

Winter barley, 334

Woad, [illegible]

Wood, [illegible], 235
- [illegible], 252
- [illegible], 241
- [illegible], 239
- [illegible], 231
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible], 242
- [illegible]
- [illegible] broad-leaved woods,
- [illegible]
- [illegible]
- [illegible]
- [illegible]

Wood, green Havana, 241
- grenadilla, 242
- hardness of, 208
- interfascicular, 291
- Itaka, 239
- Japanese nutmeg, 236
- king, 241
- lima, 252
- medullary rays of fir, 186
  - pine, 187
  - spruce, 186
- Nicaragua, 252
- of dicotyledons, 174
- of gymnosperms, 174
- palm, 243
- Palmyra, 243
- parenchyma, 176, 193, 206
  - of broad-leaved woods, 196
- partridge, 242
- Pernambuco Brazil, 252
- pheasant, 242
- primary, 178
- primavera, 241
- pulp, chemical, 118
  - mechanical, 116
  - production of, in United States, 116
  - soda, 116, 118
  - sulphite, 116, 118
- purple, 242
- red, 242
  - coral, 242
  - Havana, 242
- sappan, 252
- secondary, 178
- skewer, 235
- snake, 239
- spindle, 235
- spring, 179
- structure of, 175
- summer, 179
- tambinziran, 242
- tulip, 231, 240
- used for pulp, identification of, 293
- vacapow, 242
- violet, 240, 241
- wacapow, 242
- white, 231
- zebra, 240, 243
- [illegible], 242

Woods, analytical key to economic, 211
- [illegible], 251
- broad-leaved, of temperate zone, 196, 218
  - of tropics, 206, 239
  - tracheæ of, 196
  - tracheids of, 196
  - vessels of, 196
- color of, 207
- coniferous, 175, 211
- cork, [illegible]
- description of species of, 211

- Woods, economic, 211
  - analytical key for identification of, 211
  - hard, 213
  - physico-technical properties of 207
  - rare, 242
  - red, 252
  - soft, 213
  - tropical broad-leaved, 206, 239
  - true wood fibers of broad-leaved, 196
  - yellow, 244
- Woof, 157
- Wool, 123
  - distinction of natural-colored and dyed, 166
  - extract, 141
  - goat's, 130
  - sheep's, 124
- Woolen fabrics, examination of, 163, 164, 165, 166, 168
- *Wrightia tinctoria*, 70

- Xylem, 259

- Yam starch, 47
- Yamamai silk, 148
- Yarn, ramie, identification of, 161
  - tow, in linen cloth, 161
- Yellow birch, 236
  - cat's-paw, 323
  - fir, 215
  - locust, 220
  - moth weed, 323
  - pine, 217
  - poplar, 231
  - wood, Hungarian, 246
  - woods, 244
- Yew, 183, 193, 208, 212, 213
- Yoke elm, 232
- Young fustic, 229, 246, 249
  - distinction from old fustic 249
  - identification of, 295
- Yucatan mahogany, 241

- Zamia, 47
- Zanzibar ebony, 239
- Zebra wood, 240, 243
- *Zingiber officinale*, 266
- *Zingiberaceæ*, 262
- Zirikota wood, 24